Carrie

THE ELECTRICAL HANDBOOK

A CONVENIENT BOOK OF REFERENCE

FOR

ELECTRICIANS

First Edition

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TECHNICAL SUPPLY COMPANY

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THE ELECTRICAL HANDBOOK

USEFUL TABLES

WEIGHTS AND MEASURES

LINEAR MEASURE

12	inches (in.)	= 1 foot	ft.
3	feet	= 1 yard	yd.
5½	yards	= 1 rod	rd.
40	rods	= 1 furlong	fur.
8	furlongs	= 1 mile	mi.

in.	*ft.*	*yd.*	*rd.*	*fur.*	*mi.*
36 =	3 =	1			
198 =	16.5 =	5.5 =	1		
7,920 =	660 =	220 =	40 =	1	
63,360 =	5,280 =	1,760 =	320 =	8 =	1

SQUARE MEASURE

144	square inches (sq. in.)	= 1 square foot	sq. ft.
9	square feet	= 1 square yard	sq. yd.
30¼	square yards	= 1 square rod	sq. rd.
160	square rods	= 1 acre	A.
640	acres	= 1 square mile	sq. mi

sq. mi.	*A.*	*sq. rd.*	*sq. yd.*	*sq. ft.*	*sq. in.*
1 =	640 =	102,400 =	3,097,600 =	27,878,400 =	4,014,489,600

CUBIC MEASURE

1,728 cubic inches (cu. in.)	= 1 cubic foot	cu. ft.
27 cubic feet	= 1 cubic yard	cu. yd
128 cubic feet	= 1 cord	cd.
24¾ cubic feet	= 1 perch	P.

1 cu. yd. = 27 cu. ft. = 46,656 cu. in.

MEASURE OF ANGLES OR ARCS

60 seconds (″)	= 1 minute	′
60 minutes	= 1 degree	°
90 degrees	= 1 rt. angle or quadrant	∟
360 degrees	= 1 circle	cir.

1 cir. = 360° = 21,600′ = 1,296,000″

AVOIRDUPOIS WEIGHT

437.5 grains (gr.)	= 1 ounce	oz.
16 ounces	= 1 pound	lb.
100 pounds	= 1 hundredweight	cwt.
20 cwt., or 2,000 lb	= 1 ton	T.
2,240 lb	= 1 long ton	L. T.

1 T. = 20 cwt. = 2,000 lb. = 32,000 oz. = 14,000,000 gr.

The avoirdupois pound contains 7,000 gr.

TROY WEIGHT

24 grains (gr.)	= 1 pennyweight	pwt.
20 pennyweights	= 1 ounce	oz.
12 ounces	= 1 pound	lb.

1 lb. = 12 oz. = 240 pwt. = 5,760 gr.

DRY MEASURE

2 pints (pt.)	= 1 quart	qt.
8 quarts	= 1 peck	pk.
4 pecks	= 1 bushel	bu.

1 bu. = 4 pk. = 32 qt. = 64 pt.

The U. S. bushel contains 2,150.42 cu. in. = approximately 1¼ cu. ft. The British bushel contains 2,218.19 cu. in.

LIQUID MEASURE

4 gills (gi.)	= 1 pint	pt.
2 pints	= 1 quart	qt.
4 quarts	= 1 gallon	gal.
31½ gallons	= 1 barrel	bbl.
2 barrels, or 63 gallons	= 1 hogshead	hhd.

1 hhd. = 2 bbl. = 63 gal. = 252 qt. = 504 pt. = 2,016 gi.

The U. S. gallon contains 231 cu. in. = .134 cu. ft., nearly, or 1 cu. ft. contains 7.481 gal.

When water is at its maximum density, 1 cu. ft. weighs 62.425 lb. and 1 gallon weighs 8.345 lb.

For approximations, 1 cu. ft. of water is considered equal to 7½ gal., and 1 gal. as weighing 8⅓ lb.

THE METRIC SYSTEM

The metric system is based on the meter, which, according to the U. S. Coast and Geodetic Survey Report of 1884, is equal to 39.370432 in. The value commonly used is 39.37 in. and is authorized by the U. S. government.

There are three principal units—the *meter*, the *liter* (pronounced "lee-ter"), and the *gram*, the units of length, capacity, and weight, respectively. Multiples of these units are obtained by prefixing to the names of the principal units the Greek words *deca* (10), *hecto* (100), and *kilo* (1,000); the submultiples, or divisions, are obtained by prefixing the Latin words *deci* ($\frac{1}{10}$), *centi* ($\frac{1}{100}$), and *milli* ($\frac{1}{1000}$). These prefixes form the key to the entire system. The abbreviations of the principal units of these submultiples begin with a small letter, while those of the multiples begin with a capital letter.

MEASURES OF LENGTH

10 millimeters (mm.)	= 1 centimeter	cm.
10 centimeters	= 1 decimeter	dm.
10 decimeters	= 1 meter	m.
10 meters	= 1 decameter	Dm.
10 decameters	= 1 hectometer	Hm.
10 hectometers	= 1 kilometer	Km.

MEASURES OF SURFACE (NOT LAND)

100 square millimeters (sq. mm.)	= 1 square centimeter	sq. cm.
100 square centimeters	= 1 square decimeter	sq. dm.
100 square decimeters	= 1 square meter	sq. m.

MEASURES OF VOLUME

1,000 cubic millimeters (cu. mm.)	= 1 cubic centimeter	cu. cm.
1,000 cubic centimeters	= 1 cubic decimeter	cu. dm.
1,000 cubic decimeters	= 1 cubic meter	cu. m.

MEASURES OF CAPACITY

10 milliliters (ml.)	= 1 centiliter	cl.
10 centiliters	= 1 deciliter	dl.
10 deciliters	= 1 liter	l.
10 liters	= 1 decaliter	Dl.
10 decaliters	= 1 hectoliter	Hl.
10 hectoliters	= 1 kiloliter	Kl.

The liter is equal to the volume occupied by 1 cu. dm.

MEASURES OF WEIGHT

10 milligrams (mg.)	= 1 centigram	cg.
10 centigrams	= 1 decigram	dg.
10 decigrams	= 1 gram	g.
10 grams	= 1 decagram	Dg.
10 decagrams	= 1 hectogram	Hg.
10 hectograms	= 1 kilogram	Kg.
1,000 kilograms	= 1 ton	T.

The gram is the weight of 1 cu. cm. of pure distilled water at a temperature of 39.2° F.; the kilogram is the weight of 1 liter of water; the ton is the weight of 1 cu. m. of water.

METRIC CONVERSION FACTORS

In order to use the following factors for converting from English to metric units, it is necessary to transform the

equations; for example, 1,000 Km. × .621 = 621 mi., but 1,000 mi. ÷ .621 = 1,610 Km.

Km. × .621 = mi.
Km. ÷ 1.609 = mi.
Km. × 3,281 = ft.
m. × 39.37 = in.
m. × 3.281 = ft.
m. × 1.094 = yd.
cm. × .3937 = in.
cm. ÷ 2.54 = in.
mm. × .03937 = in.
mm. ÷ 25.4 = in.
sq. Km. × 247.1 = A.
sq. m. × 10.764 = sq. ft.
sq. cm. × .155 = sq. in.
sq. cm. ÷ 6.451 = sq. in.
sq. mm. × .00155 = sq. in.
sq. mm. ÷ 645.1 = sq. in.
cu. m. × 35.315 = cu. ft.
cu. m. × 1.308 = cu. yd.
cu. m. × 264.2 = gal. (U. S.)
cu. cm. ÷ 16.383 = cu. in.
l. × 61.022 = cu. in.
l. × .2642 = gal. (U. S.)
l. ÷ 3.78 = gal. (U. S.)
l. ÷ 28.316 = cu. ft.
g. × 15.432 = gr.
g. × 981 = dynes
g. ÷ 28.35 = oz. (avoir.)
grams per sq. cm. × 14.22 = lb. per sq. in.
Kg. × 2.205 = lb.
Kg. × 35.3 = oz. (avoir.)
Kg. × 1,102.3 = tons (2,000 lb.)
Kg. per sq. cm. × 14,223 = lb. per sq. in.
Kg.-m. × 7.233 = ft.-lb.
kilowatts (k. w.) × 1.34 = H. P.
watts ÷ 746 = H. P.
watts × .7373 = ft.-lb. per sec.
Joules × .7373 = ft.-lb.
Calorie (kilogram-degree) × 3.968 = B. T. U.
Calorie (kilogram-degree) ÷ .252 = B. T. U.
Joules × .24 = gram-calories
gram-calories × 4.19 = Joules
gravity (Paris) = 981 cm. per sec. per sec.
(Degrees centigrade × 1.8) + 32° = degrees F.

WEIGHT AND SPECIFIC GRAVITY OF VARIOUS SUBSTANCES

The specific gravity of a substance is the ratio of the weight of any volume of the substance to the weight of an equal volume of some standard substance (water, in the case of solids and liquids; and air, in the case of gases).

Metals	Weight per Cu. In. Pound	Specific Gravity
Aluminum	.096	2.660
Antimony	.242	6.712
Bismuth	.352	9.746
Brass, common	.307	8.500
Copper, cast	.314	8.700
Copper, rolled	.321	8.878
Gold, pure cast	.696	19.258
Iron, cast	.260	7.207
Iron, wrought	.281	7.780
Lead, pure	.409	11.330
Mercury, at 60° F	.491	13.580
Silver, pure	.378	10.474
Steel, hard	.286	7.919
Steel, soft	.283	7.833
Tin	.256	7.351
Zinc	.260	7.101

Stones and Earth	Weight per Cu. In. Pound	Specific Gravity
Asbestos	.1110	3 to 3.2
Brick	.0723	2.000
Chalk	.1006	2.784
Clay	.0686	1.900
Coal, anthracite	.0592	1.640
	.0519	1.436
Coal, bituminous	.0488	1.350
Earth, loose	.0491	1.360
Emery	.1450	4.000
Glass, flint	.1260	3.500
Granite, Quincy	.0958	2.652
Gypsum, opaque	.0783	2.168
Limestone	.0980	2.700
Marble, common	.0970	2.686
Mica	.1012	2.800
Quartz	.0961	2.660
Salt, common	.0769	2.130
Sand	.0957	2.650
Slate	.1012	2.800
Soil, common	.0717	1.984
Stone, common	.0910	2.520
Sulphur, native	.0734	2.033

Dry Woods	Weight per Cu. In. Pound	Specific Gravity
Ash	.0305	.845
Beech	.0308	.852
Cedar, American	.0203	.561
Cork	.0090	.250
Ebony, American	.0441	1.220
Elm	.0202	.560
Lignum vitæ	.0481	1.330
Mahogany, Honduras	.0202	.560
Maple	.0285	.790
Oak	.0343	.950
Pine, Southern	.0260	.720
Pine, White	.0144	.400
Poplar	.0138	.383
Spruce	.0181	.500

Liquids	Weight per Cu. In. Pound	Specific Gravity
Acid, nitric	.0440	1.217
Acid, sulphuric	.0665	1.841
Acid, muriatic, or hydrochloric	.0434	1.200
Alcohol, commercial	.0301	.833
Alcohol, pure	.0286	.792
Oil, linseed	.0340	.940
Oil, turpentine	.0314	.870
Water, distilled (62.425 lb. per cu. ft.)	.0361	1.000

Gases and Vapors	Weight per Cu. Ft. Grains	Specific Gravity
At 32° and a tension of 1 atmosphere		
Atmospheric air	565.11	1.0000
Ammonia gas	333.1	.5894
Carbonic acid	859.0	1.5201
Carbonic oxide	546.6	.9673
Hydrogen	39.1	.0692
Oxygen	624.8	1.1056
Sulphureted hydrogen	663.8	1.1747
Nitrogen	548.9	.9713
Steam at 212° F	275.8	.4880

The weight of a cubic foot of any solid or liquid is found by multiplying its specific gravity by 62.425 lb. avoir. The weight of a cubic foot of any gas at atmospheric pressure and at 32° F. is found by multiplying its specific gravity by .08073 lb. avoir.

CHEMISTRY AND ELECTROCHEMISTRY

Divisions of Matter.—Science assumes three divisions of matter—*masses*, *molecules*, and *atoms*. A **mass** is any portion of matter appreciable by the senses. A **molecule** is the smallest particle of matter into which a body can be divided; it is the smallest particle that is capable of separate existence. An **atom** is the still smaller particle produced by the division of a molecule by chemical means, and is regarded by chemists as the unit quantity of chemical combination. A molecule is a group of two or more atoms that are united by their affinity, or mutual attraction. *Elemental* molecules are formed of like atoms, *compound* molecules are formed of unlike atoms. Matter composed of elemental molecules is called *simple*, or *elementary matter;* matter composed of compound molecules is called *compound matter*.

The **atomic weight** of an element is the relative proportion, by weight, with which it enters into combinations with other elements. Hydrogen combines with other elements in the smallest proportion, by weight, of any of the elements. The weight of oxygen entering into a combination is 15.88 times the corresponding weight of hydrogen; i. e., if the atomic weight of hydrogen is 1, that of oxygen is 15.88, and if the atomic weight of oxygen is 16, that of hydrogen is about 1.008.

Valence.—Atoms unite in molecules always in certain fixed proportions. For example, 2 atoms of hydrogen, H, unite with 1 atom of oxygen, O, to form 1 molecule of water, H_2O; 1 atom of hydrogen, H, unites with 1 atom of chlorine, Cl, to form 1 molecule of hydrochloric acid, HCl. The **valence** of an element is the measure of its power to hold other elements in combination, and is stated on the basis that the valence of hydrogen is I. An element is mono-, di-, tri-, tetra-, etc.

SYMBOLS, ATOMIC WEIGHTS, ETC. FOR A NUMBER OF THE MORE COMMON ELEMENTS

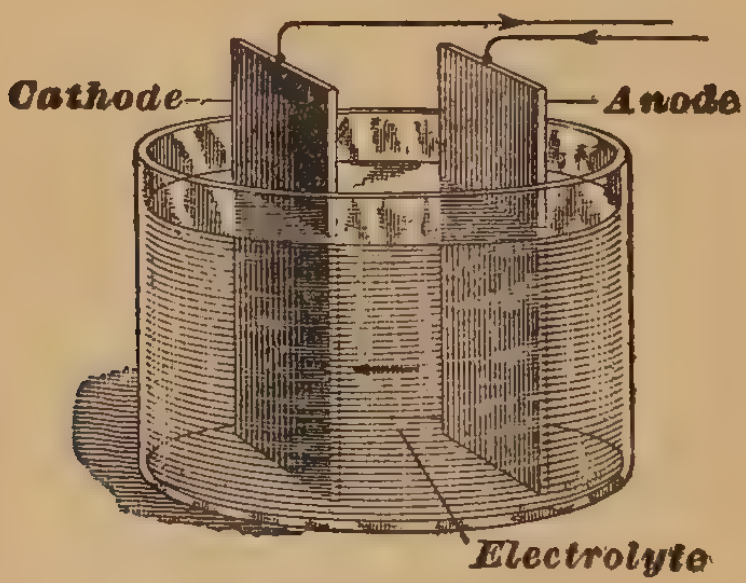
Element and Symbol	Atomic Weight	Common Valence	Chemical Equivalent
Aluminum, *Al*	27.1	III	9.03
Antimony, *Sb*	120.2	III–V	40.067— 24.04
Arsenic, *As*	75.0	III–V	25. — 15.
Barium, *Ba*	137.4	II	68.7
Bismuth, *Bi*	208.5	III–V	69.5 — 41.7
Boron, *B*	11.0	III	3.67
Bromine Br	79.96	I	79.96
Cadmium, *Cd*	112.4	II	56.2
Calcium, *Ca*	40.1	II	20.05
Carbon, *C*	12.0	IV	3.
Chlorine, *Cl*	35.45	I	35.45
Chromium, *Cr*	52.1	II–VI	26.05 — 8.68
Cobalt, *Co*	59.0	II–III	29.5 — 19.67
Copper, *Cu*	63.6	I–II	63.6 — 31.8
Fluorine, *F*	19.0	I	19.
Gold, *Au*	197.2	III	65.73
Hydrogen, *H*	1.008	I	1.008
Iodine, *I*	126.85	I	126.85
Iron, *Fe*	55.9	II–III	27.95 — 18.63
Lead, *Pb*	206.9	II–IV	103.45 — 51.73
Lithium, *Li*	7.03	I	7.03
Magnesium, *Mg*	24.36	II	12.18
Manganese, *Mn*	55.0	II–VII	27.5 — 7.86
Mercury, *Hg*	200.0	I–II	200.0 —100.0
Nickel, *Ni*	58.7	II–III	29.35 — 19.57
Nitrogen, *N*	14.04	III–V	4.68 — 2.81
Oxygen, *O*	16.0	II	8.0
Palladium, *Pd*	106.5	IV	26.63
Phosphorus, *P*	31.0	III–V	10.33 — 6.2
Platinum, *Pt*	194.8	IV	48.7
Potassium, *K*	39.15	I	39.15
Selenium Se	79.2	II	39.6
Silicon, *Si*	28.4	IV	7.1
Silver, *Ag*	107.93	I	107.93
Sodium, *Na*	23.05	I	23.05
Strontium, *Sr*	87.6	II	43.8
Sulphur, *S*	32.06	II	16.03
Tellurium, *Te*	127.6	II	63.8
Thallium, *Tl*	204.1	I–III	204.1 — 68.03
Thorium, *Th*	232.5	IV	58.13
Tin, *Sn*	119.0	II–IV	59.5 — 29.75
Tungsten, *W*	184.0	IV–VI	46.0 — 30.67
Uranium, *U*	239.5	IV–VI	59.88 — 39.92
Vanadium, *V*	51.2	III–V	17.07 — 10.24
Zinc, *Zn*	65.4	II	32.7

The names of non-metallic elements in the above table are printed in *Italics*. The atomic weights given are based on oxygen, $O = 16$.

valent according to whether its atoms hold the atoms of other elements in combination in the proportion of one, two, three, four, etc. Hydrogen is monovalent and oxygen bivalent because 1 atom of oxygen holds 2 atoms of hydrogen, as represented by the symbol H_2O. Some elements, for instance, copper, have two or more different valencies because they unite in different proportions with certain other elements to form different compounds. Thus there is cuprous chloride, $CuCl$, and cupric chloride, $CuCl_2$.

ELECTROLYTIC ACTION

A current of electricity in passing through an electrolyte decomposes it; e. g., an electrolyte consisting of zinc chloride (usually dissolved in water) is broken up into chlorine gas and metallic zinc. An electrolytic cell consists of a vessel



ELECTROLYTIC CELL

containing the electrolyte and the electrodes—the anode and the cathode; these are usually metal or carbon plates. The two parts into which the electrolyte is decomposed are called ions; those ions that appear at the anode are called *anions* and those at the cathode are called *cations*. In decomposing zinc chloride, zinc appears at the cathode and is thus a cation, and chlorine gas appears at the anode as an anion.

CHEMICAL AND ELECTROCHEMICAL EQUIVALENTS

BASED ON ATOMIC WEIGHT OF OXYGEN = 16 AND ELECTROCHEMICAL EQUIVALENT OF SILVER =.001118. THE NAMES OF NON-METALLIC ELEMENTS ARE PRINTED IN ITALICS.

Name of Element and Symbol	Common Valence	Electrochemical Equivalent Grams per Coulomb	Name of Element and Symbol	Common Valence	Electrochemical Equivalent Grams per Coulomb
Aluminum, *Al*..	III	.00009354	Mercury, *Hg* ...	I–II	.00207172—.00103586
Antimony, *Sb*..	III–V	.00041504—.00024902	Nickel, *Ni*.....	II–III	.00030402—.00020272
Arsenic, *As*.....	III–V	.00025997—.00015538	*Nitrogen*, *N*....	III–V	.00004848—.00002911
Barium, *Ba*....	II	.00071164	*Oxygen*, *O*.....	II	.00008287
Bismuth, *Bi*....	III–V	.00071992—.00043195	Palladium, *Pd*..	IV	.00027585
Boron, *B*.....	III	.00003802	*Phosphorus*,*P* ..	III–V	.00010700—.00006422
Bromine, *Br*....	I	.00082827	Platinum, *Pt*...	IV	.00050446
Cadmium, *Cd* ..	II	.00058216	Potassium, *K* ..	I	.00040554
Calcium, *Ca*....	II	.00020768	*Selenium*, *Se* ...	II	.00041020
Carbon, *C*.....	IV	.00003108	*Silicon*, *Si*.....	IV	.00075346
Chlorine, *Cl*	I	.00036721	Silver, *Ag*.....	I	.00111800
Chromium, *Cr*..	II–VI	.00026984—.00008991	Sodium, *Na*....	I	.00023877
Cobalt, *Co*	II–III	.00030558—.00020375	Strontium, *Sr*..	II	.00045371
Copper, *Cu*	I–II	.00065881—.00032940	*Sulphur*, *S*.....	II	.00016606
Fluorine, *F*.....	I	.00019681	*Tellurium*, *Te* ..	II	.00066088
Gold, *Au*.....	III	.00068087	Thallium, *Tl* ...	I–III	.00211419—.00070470
Hydrogen, *H* ...	I	.00001044	Thorium, *Th*...	IV	.00060215
Iodine, *I*.....	I	.00131399	Tin, *Sn*.....	II–IV	.00061634—.00030817
Iron, *Fe*.....	II–III	.00028952—.00019298	Tungsten, *W*...	IV–VI	.00047650—.00031769
Lead, *Pb*.....	II–IV	.00107160—.00053585	Uranium, *U*....	IV–VI	.00062027—.00041352
Lithium, *Li*....	I	.00007282	Vanadium, *V* ..	III–V	.00017682—.00010607
Magnesium, *Mg*	II	.00012617	Zinc, *Zn*.....	II	.00033873
Manganese, *Mn*	II–VII	.00028486—.00008142			

The **chemical equivalent** of an element is the quotient of the atomic weight divided by the valence. The **electrochemical equivalent** of an element is the weight in grams liberated electrolytically by 1 coulomb (1 ampere-second) of electricity. The electrochemical equivalent is proportional to the chemical equivalent. The electrochemical equivalent of silver has been accurately determined by experiment as .001118 gram, and that of each of the other elements can be calculated from this. For example, the electrochemical equivalent of aluminum is $\frac{9.03}{107.93} \times .001118 = .00009354$ gram.

HEAT

SPECIFIC HEATS OF METALS

The specific heat of a substance is the number of heat units required to raise a unit mass of the substance one degree in temperature. The specific heat of water is very nearly constant for all temperatures, but that at its temperature of maximum density (4° C. or 39.1° F.) is considered unity. The specific heats of most substances increase with increasing temperatures.

Substance	Specific Heat at		
	0° C. or 32° F.	50° C. or 122° F.	100° C. or 212° F.
Aluminum	.2070	.2185	.2300
Copper	.0901	.0923	.0966
German silver	.0941	.0947	.0952
Iron	.1060	.1130	.1200
Lead	.0300	.0315	.0331
Platinum	.0320	.0326	.0333
Platinum silver	.0473	.0487	.0581
Silver	.0547	.0569	.0591
Tin	.0523	.0568	.0595
Zinc	.0901	.0938	.0976

TEMPERATURE OF FUSION

Substance	Fusing Point, Degrees	
	F.	C.
Aluminum	1,160	627
Carbon	Infusible	Infusible
Copper	1,931	1,054
Gold	1,913	1,045
Iridium	3,542	1,950
Iron, cast	2,192	1,200
Iron, wrought	2,912	1,600
Lead	617	325
Mercury	−37.8	−38.8
Nickel	2,642	1,450
Osmium	3,900	2,200*
Platinum	3,225	1,774
Silver, pure	1,749	954
Steel	2,520	1,382
Sulphur	235	114.5
Tantalum	3,865	2,150*
Tin	551	233
Tungsten	above 3,420	above 1,900*

*J. Swinburne, F. R. S., Proc. British Institution of Electrical Engineers, Jan. 10, 1907.

HEAT UNITS

One *British thermal unit* (B. T. U.) is the quantity of heat required to raise the temperature of 1 lb. of pure water 1° F. at or near its maximum density, 39.1° F.

One *calorie* is the quantity of heat required to raise the temperature of 1 Kg. of water 1° C. at or near 4° C.

1 B. T. U. = .252 calorie and 1 calorie = 3.968 B. T. U.

One *small*, or *gram*, *calorie* (a heat unit also in some use) is the quantity of heat required to raise the temperature of 1 gram of water 1° C. at or near 4° C.

COEFFICIENTS OF LINEAR EXPANSION

The coefficient of expansion of a body is its expansion per degree rise of temperature. The coefficient of surface expansion is double, and that of cubical expansion three times, the coefficient of linear expansion.

Substance		Coefficient of Linear Expansion in Inches per Degree F.
Aluminum		.00001140
Brass		.00001040
Brick		.00000306
Cement and Concrete	from	.00000550
	to	.00000780
Copper		.00000961
Glass	from	.00000399
	to	.00000521
Gold		.00000841
Granite		.00000460
Iron, cast		.00000587
Iron, wrought		.00000677
Lead		.00001580
Marble		.00000400
Masonry	from	.00000206
	to	.00000490
Mercury		.00003334
Platinum		.00000494
Porcelain		.00000200
Sandstone	from	.00000400
	to	.00000670
Steel, untempered		.00000599
Steel, tempered		.00000702
Tin		.00001160
Wood (pine)		.00000276
Zinc		.00001634

For example, a 60-ft. steel rail in warming from 20° F. below zero to 100° F. will expand $120 \times .00000599 \times 60 \times 12 = .5175$ in.

THE MECHANICAL EQUIVALENT OF HEAT

1 B. T. U. = 778 ft.-lb.

1 ft.-lb. $= \frac{1}{778} = .001285$ B. T. U.

1 H. P. = 33,000 ft.-lb. per min. = 42.416 B. T. U. per min.

CENTIGRADE AND FAHRENHEIT DEGREES

Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.
0	32.0	26	78.8	51	123.8	76	168.8
1	33.8	27	80.6	52	125.6	77	170.6
2	35.6	28	82.4	53	127.4	78	172.4
3	37.4	29	84.2	54	129.2	79	174.2
4	39.2	30	86.0	55	131.0	80	176.0
5	41.0	31	87.8	56	132.8	81	177.8
6	42.8	32	89.6	57	134.6	82	179.6
7	44.6	33	91.4	58	136.4	83	181.4
8	46.4	34	93.2	59	138.2	84	183.2
9	48.2	35	95.0	60	140.0	85	185.0
10	50.0	36	96.8	61	141.8	86	186.8
11	51.8	37	98.6	62	143.6	87	188.6
12	53.6	38	100.4	63	145.4	88	190.4
13	55.4	39	102.2	64	147.2	89	192.2
14	57.2	40	104.0	65	149.0	90	194.0
15	59.0	41	105.8	66	150.8	91	195.8
16	60.8	42	107.6	67	152.6	92	197.6
17	62.6	43	109.4	68	154.4	93	199.4
18	64.4	44	111.2	69	156.2	94	201.2
19	66.2	45	113.0	70	158.0	95	203.0
20	68.0	46	114.8	71	159.8	96	204.8
21	69.8	47	116.6	72	161.6	97	206.6
22	71.6	48	118.4	73	163.4	98	208.4
23	73.4	49	120.2	74	165.2	99	210.2
24	75.2	50	122.0	75	167.0	100	212.0
25	77.0						

TEMPERATURE

The temperature of a body is its degree of sensible heat For the measurement of temperatures there are three kinds of thermometers: the Fahrenheit, abbreviated F. or Fahr., commonly used in America; the Centigrade, abbreviated C. or Cent., used in France and by scientists everywhere; and the Réaumur, abbreviated R. or Réau., used in Germany.

Standard Points	*Degrees F.*	*Degrees C.*	*Degrees R.*
Boiling point of water at sea level; i. e., pressure = 1 atmosphere.....	212	100	80
Melting point of ice.....	32	0	0
Absolute zero, i. e., the total absence of heat; theoretical only.....	−460	−273	−219

Between boiling point and freezing point = 180° F. = 100° C. = 80° R.

$$\text{Temp. F.} = \frac{9}{5}\,\text{Temp. C.} + 32^\circ = \frac{9}{4}\,\text{Temp. R.} + 32^\circ.$$

$$\text{Temp. C.} = \frac{5}{9}\,(\text{Temp. F.} - 32^\circ) = \frac{5}{4}\,\text{Temp. R.}$$

$$\text{Temp. R.} = \frac{4}{9}\,(\text{Temp. F.} - 32^\circ) = \frac{4}{5}\,\text{Temp. C.}$$

MATHEMATICAL TABLES

CIRCUMFERENCES AND AREAS OF CIRCLES FROM 1-64 TO 100

Diam.	Circum.	Area	Diam.	Circum.	Area
1/64	.0491	.0002	4	12.5664	12.5664
1/32	.0982	.0008	4 1/8	12.9591	13.3641
3/64	.1963	.0031	4 1/4	13.3518	14.1863
1/16	.3927	.0123	4 3/8	13.7445	15.0330
5/64	.5890	.0276	4 1/2	14.1372	15.9043
3/32	.7854	.0491	4 5/8	14.5299	16.8002
7/64	.9817	.0767	4 3/4	14.9226	17.7206
1/8	1.1781	.1104	4 7/8	15.3153	18.6555
9/64	1.3744	.1503	5	15.7080	19.6350
5/32	1.5708	.1963	5 1/8	16.1007	20.6290
11/64	1.7671	.2485	5 1/4	16.4934	21.6476
3/16	1.9635	.3068	5 3/8	16.8861	22.6907
13/64	2.1598	.3712	5 1/2	17.2788	23.7583
7/32	2.3562	.4418	5 5/8	17.6715	24.8505
15/64	2.5525	.5185	5 3/4	18.0642	25.9673
1/4	2.7489	.6013	5 7/8	18.4569	27.1086
17/64	2.9452	.6903	6	18.8496	28.2744
1	3.1416	.7854	6 1/8	19.2423	29.4648
1 1/8	3.5343	.9940	6 1/4	19.6350	30.6797
1 1/4	3.9270	1.2272	6 3/8	20.0277	31.9191
1 3/8	4.3197	1.4849	6 1/2	20.4204	33.1831
1 1/2	4.7124	1.7671	6 5/8	20.8131	34.4717
1 5/8	5.1051	2.0739	6 3/4	21.2058	35.7848
1 3/4	5.4978	2.4053	6 7/8	21.5985	37.1224
1 7/8	5.8905	2.7612	7	21.9912	38.4846
2	6.2832	3.1416	7 1/8	22.3839	39.8713
2 1/8	6.6759	3.5466	7 1/4	22.7766	41.2826
2 1/4	7.0686	3.9761	7 3/8	23.1693	42.7184
2 3/8	7.4613	4.4301	7 1/2	23.5620	44.1787
2 1/2	7.8540	4.9087	7 5/8	23.9547	45.6636
2 5/8	8.2467	5.4119	7 3/4	24.3474	47.1731
2 3/4	8.6394	5.9396	7 7/8	24.7401	48.7071
2 7/8	9.0321	6.4918	8	25.1328	50.2656
3	9.4248	7.0686	8 1/8	25.5255	51.8487
3 1/8	9.8175	7.6699	8 1/4	25.9182	53.4563
3 1/4	10.2102	8.2958	8 3/8	26.3109	55.0884
3 3/8	10.6029	8.9462	8 1/2	26.7036	56.7451
3 1/2	10.9956	9.6211	8 5/8	27.0963	58.4264
3 5/8	11.3883	10.3206	8 3/4	27.4890	60.1322
3 3/4	11.7810	11.0447	8 7/8	27.8817	61.8625
3 7/8	12.1737	11.7933	9	28.2744	63.6174

TABLE—(*Continued*)

Diam.	Circum.	Area	Diam.	Circum.	Area
9⅛	28.6671	65.3968	19½	61.2612	298.648
9¼	29.0598	67.2008	19¾	62.0466	306.355
9⅜	29.4525	69.0293	20	62.8320	314.160
9½	29.8452	70.8823	20¼	63.6174	322.063
9⅝	30.2379	72.7599	20½	64.4028	330.064
9¾	30.6306	74.6621	20¾	65.1882	338.164
9⅞	31.0233	76.589	21	65.9736	346.361
10	31.4160	78.540	21¼	66.7590	354.657
10¼	32.2014	82.516	21½	67.5444	363.051
10½	32.9868	86.590	21¾	68.3298	371.543
10¾	33.7722	90.763	22	69.1152	380.134
11	34.5576	95.033	22¼	69.9006	388.822
11¼	35.3430	99.402	22½	70.6860	397.609
11½	36.1284	103.869	22¾	71.4714	406.494
11¾	36.9138	108.434	23	72.2568	415.477
12	37.6992	113.098	23¼	73.0422	424.558
12¼	38.4846	117.859	23½	73.8276	433.737
12½	39.2700	122.719	23¾	74.6130	443.015
12¾	40.0554	127.677	24	75.3984	452.390
13	40.8408	132.733	24¼	76.1838	461.864
13¼	41.6262	137.887	24½	76.9692	471.436
13½	42.4116	143.139	24¾	77.7546	481.107
13¾	43.1970	148.490	25	78.5400	490.875
14	43.9824	153.938	25¼	79.3254	500.742
14¼	44.7678	159.485	25½	80.1108	510.706
14½	45.5532	165.130	25¾	80.8962	520.769
14¾	46.3386	170.874	26	81.6816	530.930
15	47.1240	176.715	26¼	82.4670	541.190
15¼	47.9094	182.655	26½	83.2524	551.547
15½	48.6948	188.692	26¾	84.0378	562.003
15¾	49.4802	194.828	27	84.8232	572.557
16	50.2656	201.062	27¼	85.6086	583.209
16¼	51.0510	207.395	27½	86.3940	593.959
16½	51.8364	213.825	27¾	87.1794	604.807
16¾	52.6218	220.354	28	87.9648	615.754
17	53.4072	226.981	28¼	88.7502	626.798
17¼	54.1926	233.706	28½	89.5356	637.941
17½	54.9780	240.529	28¾	90.3210	649.182
17¾	55.7634	247.450	29	91.1064	660.521
18	56.5488	254.470	29¼	91.8918	671.959
18¼	57.3342	261.587	29½	92.6772	683.494
18½	58.1196	268.803	29¾	93.4626	695.128
18¾	58.9050	276.117	30	94.2480	706.860
19	59.6904	283.529	30¼	95.0334	718.690
19¼	60.4758	291.040	30½	95.8188	730.618

TABLE—(*Continued*)

Diam.	Circum.	Area	Diam.	Circum.	Area
30¾	96.6042	742.645	42	131.947	1,385.450
31	97.3896	754.769	42¼	132.733	1,401.990
31¼	98.1750	766.992	42½	133.518	1,418.630
31½	98.9604	779.313	42¾	134.303	1,435.370
31¾	99.7458	791.732	43	135.089	1,452.200
32	100.5312	804.250	43¼	135.874	1,469.140
32¼	101.3166	816.865	43½	136.660	1,486.170
32½	102.1020	829.579	43¾	137.445	1,503.300
32¾	102.8874	842.391	44	138.230	1,520.530
33	103.673	855.301	44¼	139.016	1,537.860
33¼	104.458	868.309	44½	139.801	1,555.29
33½	105.244	881.415	44¾	140.587	1,572.81
33¾	106.029	894.620	45	141.372	1,590.43
34	106.814	907.922	45¼	142.157	1,608.16
34¼	107.600	921.323	45½	142.943	1,625.97
34½	108.385	934.822	45¾	143.728	1,643.89
34¾	109.171	948.420	46	144.514	1,661.91
35	109.956	962.115	46¼	145.299	1,680.02
35¼	110.741	975.909	46½	146.084	1,698.23
35½	111.527	989.800	46¾	146.870	1,716.54
35¾	112.312	1,003.790	47	147.655	1,734.95
36	113.098	1,017.878	47¼	148.441	1,753.45
36¼	113.883	1,032.065	47½	149.226	1,772.06
36½	114.668	1,046.349	47¾	150.011	1,790.76
36¾	115.454	1,060.732	48	150.797	1,809.56
37	116.239	1,075.213	48¼	151.582	1,828.46
37¼	117.025	1,089.792	48½	152.368	1,847.46
37½	117.810	1,104.469	48¾	153.153	1,866.55
37¾	118.595	1,119.244	49	153.938	1,885.75
38	119.381	1,134.118	49¼	154.724	1,905.04
38¼	120.166	1,149.089	49½	155.509	1,924.43
38½	120.952	1,164.159	49¾	156.295	1,943.91
38¾	121.737	1,179.327	50	157.080	1,963.50
39	122.522	1,194.593	50½	158.651	2,002.97
39¼	123.308	1,209.958	51	160.222	2,042.83
39½	124.093	1,225.420	51½	161.792	2,083.08
39¾	124.879	1,240.981	52	163.363	2,123.72
40	125.664	1,256.640	52½	164.934	2,164.76
40¼	126.449	1,272.400	53	166.505	2,206.19
40½	127.235	1,288.250	53½	168.076	2,248.01
40¾	128.020	1,304.210	54	169.646	2,290.23
41	128.806	1,320.260	54½	171.217	2,332.83
41¼	129.591	1,336.410	55	172.788	2,375.83
41½	130.376	1,352.660	55½	174.359	2,419.23
41¾	131.162	1,369.000	56	175.930	2,463.01

TABLE—(*Continued*)

Diam.	Circum.	Area	Diam.	Circum.	Area
56½	177.500	2,507.19	78½	246.616	4,839.83
57	179.071	2,551.76	79	248.186	4,901.68
57½	180.642	2,596.73	79½	249.757	4,963.92
58	182.213	2,642.09	80	251.328	5,026.56
58½	183.784	2,687.84	80½	252.899	5,089.59
59	185.354	2,733.98	81	254.470	5,153.01
59½	186.925	2,780.51	81½	256.040	5,216.82
60	188.496	2,827.44	82	257.611	5,281.03
60½	190.067	2,874.76	82½	259.182	5,345.63
61	191.638	2,922.47	83	260.753	5,410.62
61½	193.208	2,970.58	83½	262.324	5,476.01
62	194.779	3,019.08	84	263.894	5,541.78
62½	196.350	3,067.97	84½	265.465	5,607.95
63	197.921	3,117.25	85	267.036	5,674.51
63½	199.492	3,166.93	85½	268.607	5,741.47
64	201.062	3,217.00	86	270.178	5,808.82
64½	202.633	3,267.46	86½	271.748	5,876.56
65	204.204	3,318.31	87	273.319	5,944.69
65½	205.775	3,369.56	87½	274.890	6,013.22
66	207.346	3,421.20	88	276.461	6,082.14
66½	208.916	3,473.24	88½	278.032	6,151.45
67	210.487	3,525.66	89	279.602	6,221.15
67½	212.058	3,578.48	89½	281.173	6,291.25
68	213.629	3,631.69	90	282.744	6,361.74
68½	215.200	3,685.29	90½	284.315	6,432.62
69	216.770	3,739.29	91	285.886	6,503.90
69½	218.341	3,793.68	91½	287.456	6,575.56
70	219.912	3,848.46	92	289.027	6,647.63
70½	221.483	3,903.63	92½	290.598	6,720.08
71	223.054	3,959.20	93	292.169	6,792.92
71½	224.624	4,015.16	93½	293.740	6,866.16
72	226.195	4,071.51	94	295.310	6,939.79
72½	227.766	4,128.26	94½	296.881	7,013.82
73	229.337	4,185.40	95	298.452	7,088.24
73½	230.908	4,242.93	95½	300.023	7,163.04
74	232.478	4,300.85	96	301.594	7,238.25
71½	234.049	4,359.17	96½	303.164	7,313.84
75	235.620	4,417.87	97	304.735	7,389.83
75½	237.191	4,476.98	97½	306.306	7,466.21
76	238.762	4,536.47	98	307.877	7,542.98
76½	240.332	4,596.36	98½	309.448	7,620.15
77	241.903	4,656.64	99	311.018	7,697.71
77½	243.474	4,717.31	99½	312.589	7,775.66
78	245.045	4,778.37	100	314.160	7,854.00

DECIMAL EQUIVALENTS OF PARTS OF ONE INCH

1–64	.015625	17–64	.265625	33–64	.515625	49–64	.765625
1–32	.031250	9–32	.281250	17–32	.531250	25–32	.781250
3–64	.046875	19–64	.296875	35–64	.546875	51–64	.796875
1–16	.062500	5–16	.312500	9–16	.562500	13–16	.812500
5–64	.078125	21–64	.328125	37–64	.578125	53–64	.828125
3–32	093750	11–32	.343750	19–32	.593750	27–32	.843750
7–64	.109375	23–64	.359375	39–64	.609375	55–64	.859375
1–8	.125000	3–8	.375000	5–8	.625000	7–8	.875000
9–64	.140625	25–64	.390625	41–64	.640625	57–64	.890625
5–32	.156250	13–32	.406250	21–32	.656250	29–32	.906250
11–64	.171875	27–64	.421875	43–64	.671875	59–64	.921875
3–16	.187500	7–16	.437500	11–16	.687500	15–16	.937500
13–64	.203125	29–64	.453125	45–64	.703125	61–64	.953125
7–32	.218750	15–32	.468750	23–32	.718750	31–32	.968750
15–64	.234375	31–64	.484375	47–64	.734375	63–64	.984375
1–4	.250000	1–2	.500000	3–4	.750000	1	1

TRIGONOMETRIC FUNCTIONS

The table given on pages 25–29 contains the natural sines, cosines, tangents, and cotangents of angles from 0° to 90°. Angles less than 45° are given in the first column at the left-hand side of the page, and the names of the functions are given at the top of the page; angles greater than 45° appear at the right-hand side of the page, and the names of the functions are given at the bottom. Thus, the second column contains the sines of angles less than 45° and the cosines of angles greater than 45°; the sixth column contains the cotangents of angles less than 45° and the tangents of angles greater than 45°. To find the function of an angle less than 45°, look in the column of angles at the left of the page for the angle, and at the top of the page for the name of the function; to find a function of an angle greater than 45°, look in the column at the right of the page for the angle and at the bottom of the page for the name of the function. The successive angles differ by an interval of 10′; they increase downwards in the left-hand column and upwards in the right-hand column. Thus, for angles less than 45° read down from top of page, and for angles greater than 45° read up from bottom of page.

The third, fifth, seventh, and ninth columns, headed *d*, contain the differences between the successive functions; for

example, the sine of 32° 10′ is .5324 and the sine of 32° 20′ is .5348, as given in the second column, page 26; the difference is .5348 − .5324 = .0024, and the 24 is written in the third column, just opposite the space between .5324 and .5348. In like manner, the differences between the successive tabular values of the tangents are given in the fifth column, those between the cotangents in the seventh column, and those for the cosines in the ninth column. These differences in the functions correspond to a difference of 10′ in the angle; thus, when the angle 32° 10′ is increased by 10′, that is, to 32° 20′, the increase of the sine is .0024, or, as given in the table, 24. In the tabular difference, no attention is paid to the decimal point, it being understood that the difference is merely the number obtained by subtracting the last two or three figures of the smaller function from those of the larger. These differences are used to obtain the sines, cosines, etc. of angles not given in the table; for example, to find the tangent of 27° 34′ find in the table the tangent of 27° 30′, .5206, and (in column 5) the difference for 10′, 37. Difference for 1′ is 37 ÷ 10 = 3.7, and difference for 4′ is 3.7 × 4 = 14.8. Adding this difference to the value of the tan 27° 30′, gives

tan 27° 30′ = .5206
difference for 4′ = 14.8

tan 27° 34′ = .52208, or .5221, to four places.

Since only four decimal places are retained, the 8 in the fifth place is dropped and the figure in the fourth place is increased by 1, because 8 is greater than 5.

To avoid multiplication, the column of proportional parts, headed P. P., at the extreme right of the page, is used. At the head of each table in this column is the difference for 10′, and below are the differences for any intermediate number of minutes from 1′ to 9′. In the above example, the difference at 27° 30′ for 10′ was 37; looking in the table with 37 at the head, the difference opposite 4 is 14.8; that opposite 7 is 25.9; and so on. For want of space, the differences for the cotangents for angles less than 45° (or the tangents of angles greater than 45°) have been omitted from the tables of proportional parts. The use of these functions should be

°	′	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.		P. P.
0	0	0.0000		0.0000		infinit.		1.0000	0	0 90	
	10	0.0029	29	0.0029	29	343.7737		1.0000	0	50	
	20	0.0058	29	0.0058	29	171.8854		1.0000	0	40	30
	30	0.0087	29	0.0087	29	114.5887		1.0000	1	30	1 | 3.0
	40	0.0116	29	0.0116	29	85.9398		0.9999	0	20	2 | 6.0
	50	0.0145	30	0.0145	30	68.7501		0.9999	1	10	3 | 9.0
1	0	0.0175	29	0.0175	29	57.2900		0.9998	0	0 89	4 | 12.0
	10	0.0204	29	0.0204	29	49.1039	81861	0.9998	1	50	5 | 15.0
	20	0.0233	29	0.0233	29	42.9641	61398	0.9997	0	40	6 | 18.0
	30	0.0262	29	0.0262	29	38.1885	47756	0.9997	1	30	7 | 21.0
	40	0.0291	29	0.0291	29	34.3678	38207	0.9996	1	20	8 | 24.0
	50	0.0320	29	0.0320	29	31.2416	31262	0.9995	1	10	9 | 27.0
2	0	0.0349	29	0.0349	29	28.6363	26053	0.9994	1	0 88	
	10	0.0378	29	0.0378	29	26.4316	22047	0.9993	1	50	29
	20	0.0407	29	0.0407	30	24.5418	18898	0.9992	2	40	·1 | 2.9
	30	0.0436	29	0.0437	29	22.9038	16380	0.9990	1	30	2 | 5.8
	40	0.0465	29	0.0466	29	21.4704	14334	0.9989	1	20	3 | 8.7
	50	0.0494	29	0.0495	29	20.2056	12648	0.9988	1	10	4 | 11.6
3	0	0.0523	29	0.0524	29	19.0811	11245	0.9986	2	0 87	5 | 14.5
	10	0.0552	29	0.0553	29	18.0750	10061	0.9985	1	50	6 | 17.4
	20	0.0581	29	0.0582	30	17.1693	9057	0.9983	2	40	7 | 20.3
	30	0.0610	30	0.0612	29	16.3499	8194	0.9981	2	30	8 | 23.2
	40	0.0640	29	0.0641	29	15.6048	7451	0.9980	1	20	9 | 26.1
	50	0.0669	29	0.0670	29	14.9244	6804	0.9978	2	10	
4	0	0.0698	29	0.0699	30	14.3007	6237	0.9976	2	0 86	28
	10	0.0727	29	0.0729	29	13.7267	5740	0.9974	2	50	1 | 2.8
	20	0.0756	29	0.0758	29	13.1969	5298	0.9971	3	40	2 | 5.6
	30	0.0785	29	0.0787	29	12.7062	4907	0.9969	2	30	3 | 8.4
	40	0.0814	29	0.0816	30	12.2505	4557	0.9967	2	20	4 | 11.2
	50	0.0843	29	0.0846	29	11.8262	4243	0.9964	3	10	5 | 14.0
5	0	0.0872	29	0.0875	29	11.4301	3961	0.9962	2	0 85	6 | 16.8
	10	0.0901	28	0.0904	30	11.0594	3707	0.9959	3	50	7 | 19.6
	20	0.0929	29	0.0934	29	10.7119	3475	0.9957	2	40	8 | 22.4
	30	0.0958	29	0.0963	29	10.3854	3265	0.9954	3	30	9 | 25.2
	40	0.0987	29	0.0992	30	10.0780	3074	0.9951	3	20	
	50	0.1016	29	0.1022	29	9.7882	2898	0.9948	3	10	5
6	0	0.1045	29	0.1051	29	9.5144	2738	0.9945	3	0 84	1 | 0.5
	10	0.1074	29	0.1080	30	9.2553	2591	0.9942	3	50	2 | 1.0
	20	0.1103	29	0.1110	29	9.0098	2455	0.9939	3	40	3 | 1.5
	30	0.1132	29	0.1139	30	8.7769	2329	0.9936	3	30	4 | 2.0
	40	0.1161	29	0.1169	29	8.5555	2214	0.9932	4	20	5 | 2.5
	50	0.1190	29	0.1198	30	8.3450	2105	0.9929	3	10	6 | 3.0
7	0	0.1219	29	0.1228	29	8.1443	2007	0.9925	4	0 83	7 | 3.5
	10	0.1248	28	0.1257	30	7.9530	1913	0.9922	3	50	8 | 4.0
	20	0.1276	29	0.1287	30	7.7704	1826	0.9918	4	40	9 | 4.5
	30	0.1305	29	0.1317	29	7.5958	1746	0.9914	4	30	
	40	0.1334	29	0.1346	30	7.4287	1671	0.9911	3	20	4
	50	0.1363	29	0.1376	29	7.2687	1600	0.9907	4	10	1 | 0.4
8	0	0.1392	29	0.1405	30	7.1154	1533	0.9903	4	0 82	2 | 0.8
	10	0.1421	28	0.1435	30	6.9682	1472	0.9899	4	50	3 | 1.2
	20	0.1449	29	0.1465	30	6.8269	1413	0.9894	5	40	4 | 1.6
	30	0.1478	29	0.1495	29	6.6912	1357	0.9890	4	30	5 | 2.0
	40	0.1507	29	0.1524	30	6.5606	1306	0.9886	4	20	6 | 2.4
	50	0.1536	28	0.1554	30	6.4348	1258	0.9881	5	10	7 | 2.8
9	0	0.1564		0.1584		6.3138	1210	0.9877	4	0 81	8 | 3.2
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	′ °	9 | 3.6
											P. P.

°	′	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.		
9	0	0.1564		0.1584		6.3138		0.9877		0	81
			29		30		1168		5		
	10	0.1593		0.1614		6.1970		0.9872		50	
			29		30		1126		4		
	20	0.1622		0.1644		6.0844		0.9868		40	
			28		29		1086		5		
	30	0.1650		0.1673		5.9758		0.9863		30	
			29		30		1050		5		
	40	0.1679		0.1703		5.8708		0.9858		20	
			29		30		1014		5		
	50	0.1708		0.1733		5.7694		0.9853		10	
			28		30		981		5		
10	0	0.1736		0.1763		5.6713		0.9848		0	80
			29		30		949		5		
	10	0.1765		0.1793		5.5764		0.9843		50	
			29		30		919		5		
	20	0.1794		0.1823		5.4845		0.9838		40	
			28		30		890		5		
	30	0.1822		0.1853		5.3955		0.9833		30	
			29		30		862		6		
	40	0.1851		0.1883		5.3093		0.9827		20	
			29		31		836		5		
	50	0.1880		0.1914		5.2257		0.9822		10	
			28		30		811		6		
11	0	0.1908		0.1944		5.1446		0.9816		0	79
			29		30		788		5		
	10	0.1937		0.1974		5.0658		0.9811		50	
			28		30		764		6		
	20	0.1965		0.2004		4.9894		0.9805		40	
			29		31		742		6		
	30	0.1994		0.2035		4.9152		0.9799		30	
			28		30		722		6		
	40	0.2022		0.2065		4.8430		0.9793		20	
			29		30		701		6		
	50	0.2051		0.2095		4.7729		0.9787		10	
			28		31		683		6		
12	0	0.2079		0.2126		4.7046		0.9781		0	78
			29		30		664		6		
	10	0.2108		0.2156		4.6382		0.9775		50	
			28		30		646		6		
	20	0.2136		0.2186		4.5736		0.9769		40	
			28		31		629		6		
	30	0.2164		0.2217		4.5107		0.9763		30	
			29		30		613		6		
	40	0.2193		0.2247		4.4494		0.9757		20	
			28		31		597		7		
	50	0.2221		0.2278		4.3897		0.9750		10	
			29		31		582		6		
13	0	0.2250		0.2309		4.3315		0.9744		0	77
			28		30		568		7		
	10	0.2278		0.2339		4.2747		0.9737		50	
			28		31		554		7		
	20	0.2306		0.2370		4.2193		0.9730		40	
			28		31		540		6		
	30	0.2334		0.2401		4.1653		0.9724		30	
			29		31		527		7		
	40	0.2363		0.2432		4.1126		0.9717		20	
			28		30		515		7		
	50	0.2391		0.2462		4.0611		0.9710		10	
			28		31		503		7		
14	0	0.2419		0.2493		4.0108		0.9703		0	76
			28		31		491		7		
	10	0.2447		0.2524		3.9617		0.9696		50	
			29		31		481		7		
	20	0.2476		0.2555		3.9136		0.9689		40	
			28		31		469		8		
	30	0.2504		0.2586		3.8667		0.9681		30	
			28		31		459		7		
	40	0.2532		0.2617		3.8208		0.9674		20	
			28		31		448		7		
	50	0.2560		0.2648		3.7760		0.9667		10	
			28		31		439		8		
15	0	0.2588		0.2679		3.7321		0.9659		0	75
			28		32		430		7		
	10	0.2616		0.2711		3.6891		0.9652		50	
			28		31		421		8		
	20	0.2644		0.2742		3.6470		0.9644		40	
			28		31		411		8		
	30	0.2672		0.2773		3.6059		0.9636		30	
			28		32		403		8		
	40	0.2700		0.2805		3.5656		0.9628		20	
			28		31		395		7		
	50	0.2728		0.2836		3.5261		0.9621		10	
			28		31		387		8		
16	0	0.2756		0.2867		3.4874		0.9613		0	74
			28		32		379		8		
	10	0.2784		0.2899		3.4495		0.9605		50	
			28		32		371		9		
	20	0.2812		0.2931		3.4124		0.9596		40	
			28		31		365		8		
	30	0.2840		0.2962		3.3759		0.9588		30	
			28		32		357		8		
	40	0.2868		0.2994		3.3402		0.9580		20	
			28		32		350		8		
	50	0.2896		0.3026		3.3052		0.9572		10	
			28		31		343		9		
17	0	0.2924		0.3057		3.2709		0.9563		0	73
			28		32		338		8		
	10	0.2952		0.3089		3.2371		0.9555		50	
			27		32		330		9		
	20	0.2979		0.3121		3.2041		0.9546		40	
			28		32		325		9		
	30	0.3007		0.3153		3.1716		0.9537		30	
			28		32		319		9		
	40	0.3035		0.3185		3.1397		0.9528		20	
			27		32		313		8		
	50	0.3062		0.3217		3.1084		0.9520		10	
			28		32		307		9		
18	0	0.3090		0.3249		3.0777		0.9511		0	72
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	′	°

P. P.

	32	31	30
1	3.2	3.1	3.0
2	6.4	6.2	6.0
3	9.6	9.3	9.0
4	12.8	12.4	12.0
5	16.0	15.5	15.0
6	19.2	18.6	18.0
7	22.4	21.7	21.0
8	25.6	24.8	24.0
9	28.8	27.9	27.0

	29	28	27
1	2.9	2.8	2.7
2	5.8	5.6	5.4
3	8.7	8.4	8.1
4	11.6	11.2	10.8
5	14.5	14.0	13.5
6	17.4	16.8	16.2
7	20.3	19.6	18.9
8	23.2	22.4	21.6
9	26.1	25.2	24.3

	9	8
1	0.9	0.8
2	1.8	1.6
3	2.7	2.4
4	3.6	3.2
5	4.5	4.0
6	5.4	4.8
7	6.3	5.6
8	7.2	6.4
9	8.1	7.2

	7	6
1	0.7	0.6
2	1.4	1.2
3	2.1	1.8
4	2.8	2.4
5	3.5	3.0
6	4.2	3.6
7	4.9	4.2
8	5.6	4.8
9	6.3	5.4

	5	4
1	0.5	0.4
2	1.0	0.8
3	1.5	1.2
4	2.0	1.6
5	2.5	2.0
6	3.0	2.4
7	3.5	2.8
8	4.0	3.2
9	4.5	3.6

P. P.

°	′	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.			P. P.
18	0	0.3090		0.3249		3.0777		0.9511		0	72	
	10	0.3118	28	0.3281	32	3.0475	302	0.9502	9	50		
	20	0.3145	27	0.3314	33	3.0178	297	0.9492	10	40		37 | 36 | 35
	30	0.3173	28	0.3346	32	2.9887	291	0.9483	9	30		1 | 3.7 | 3.6 | 3.5
	40	0.3201	28	0.3378	32	2.9600	287	0.9474	9	20		2 | 7.4 | 7.2 | 7.0
	50	0.3228	27	0.3411	33	2.9319	281	0.9465	9	10		3 | 11.1 | 10.8 | 10.5
19	0	0.3256	28	0.3443	32	2.9042	277	0.9455	10	0	71	4 | 14.8 | 14.4 | 14.0
	10	0.3283	27	0.3476	33	2.8770	272	0.9446	9	50		5 | 18.5 | 18.0 | 17.5
	20	0.3311	28	0.3508	32	2.8502	268	0.9436	10	40		6 | 22.2 | 21.6 | 21.0
	30	0.3338	27	0.3541	33	2.8239	263	0.9426	10	30		7 | 25.9 | 25.2 | 24.5
	40	0.3365	27	0.3574	33	2.7980	259	0.9417	9	20		8 | 29.6 | 28.8 | 28.0
	50	0.3393	28	0.3607	33	2.7725	255	0.9407	10	10		9 | 33.3 | 32.4 | 31.5
20	0	0.3420	27	0.3640	33	2.7475	250	0.9397	10	0	70	
	10	0.3448	28	0.3673	33	2.7228	247	0.9387	10	50		34 | 33 | 32
	20	0.3475	27	0.3706	33	2.6985	243	0.9377	10	40		1 | 3.4 | 3.3 | 3.2
	30	0.3502	27	0.3739	33	2.6746	239	0.9367	10	30		2 | 6.8 | 6.6 | 6.4
	40	0.3529	27	0.3772	33	2.6511	235	0.9356	11	20		3 | 10.2 | 9.9 | 9.6
	50	0.3557	28	0.3805	33	2.6279	232	0.9346	10	10		4 | 13.6 | 13.2 | 12.8
21	0	0.3584	27	0.3839	34	2.6051	228	0.9336	10	0	69	5 | 17.0 | 16.5 | 16.0
	10	0.3611	27	0.3872	33	2.5826	225	0.9325	11	50		6 | 20.4 | 19.8 | 19.2
	20	0.3638	27	0.3906	34	2.5605	221	0.9315	10	40		7 | 23.8 | 23.1 | 22.4
	30	0.3665	27	0.3939	33	2.5386	219	0.9304	11	30		8 | 27.2 | 26.4 | 25.6
	40	0.3692	27	0.3973	34	2.5172	214	0.9293	11	20		9 | 30.6 | 29.7 | 28.8
	50	0.3719	27	0.4006	33	2.4960	212	0.9283	10	10		
22	0	0.3746	27	0.4040	34	2.4751	209	0.9272	11	0	68	28 | 27 | 26
	10	0.3773	27	0.4074	34	2.4545	206	0.9261	11	50		1 | 2.8 | 2.7 | 2.6
	20	0.3800	27	0.4108	34	2.4342	203	0.9250	11	40		2 | 5.6 | 5.4 | 5.2
	30	0.3827	27	0.4142	34	2.4142	200	0.9239	11	30		3 | 8.4 | 8.1 | 7.8
	40	0.3854	27	0.4176	34	2.3945	197	0.9228	12	20		4 | 11.2 | 10.8 | 10.4
	50	0.3881	26	0.4210	35	2.3750	195	0.9216	11	10		5 | 14.0 | 13.5 | 13.0
23	0	0.3907	27	0.4245	34	2.3559	191	0.9205	11	0	67	6 | 16.8 | 16.2 | 15.6
	10	0.3934	27	0.4279	35	2.3369	190	0.9194	12	50		7 | 19.6 | 18.9 | 18.2
	20	0.3961	26	0.4314	34	2.3183	186	0.9182	11	40		8 | 22.4 | 21.6 | 20.8
	30	0.3987	27	0.4348	35	2.2998	185	0.9171	12	30		9 | 25.2 | 24.3 | 23.4
	40	0.4014	27	0.4383	34	2.2817	181	0.9159	12	20		
	50	0.4041	26	0.4417	35	2.2637	180	0.9147	12	10		13 | 12
24	0	0.4067	27	0.4452	35	2.2460	177	0.9135	11	0	66	1 | 1.3 | 1.2
	10	0.4094	26	0.4487	35	2.2286	174	0.9124	12	50		2 | 2.6 | 2.4
	20	0.4120	27	0.4522	35	2.2113	173	0.9112	12	40		3 | 3.9 | 3.6
	30	0.4147	26	0.4557	35	2.1943	170	0.9100	12	30		4 | 5.2 | 4.8
	40	0.4173	27	0.4592	36	2.1775	168	0.9088	13	20		5 | 6.5 | 6.0
	50	0.4200	26	0.4628	35	2.1609	166	0.9075	12	10		6 | 7.8 | 7.2
25	0	0.4226	27	0.4663	36	2.1445	164	0.9063	12	0	65	7 | 9.1 | 8.4
	10	0.4253	26	0.4699	35	2.1283	162	0.9051	13	50		8 | 10.4 | 9.6
	20	0.4279	26	0.4734	36	2.1123	160	0.9038	12	40		9 | 11.7 | 10.8
	30	0.4305	26	0.4770	36	2.0965	158	0.9026	13	30		
	40	0.4331	27	0.4806	35	2.0809	156	0.9013	12	20		11 | 10 | 9
	50	0.4358	26	0.4841	36	2.0655	154	0.9001	13	10		1 | 1.1 | 1.0 | 0.9
26	0	0.4384	26	0.4877	36	2.0503	152	0.8988	13	0	64	2 | 2.2 | 2.0 | 1.8
	10	0.4410	26	0.4913	37	2.0353	150	0.8975	13	50		3 | 3.3 | 3.0 | 2.7
	20	0.4436	26	0.4950	36	2.0204	149	0.8962	13	40		4 | 4.4 | 4.0 | 3.6
	30	0.4462	26	0.4986	36	2.0057	147	0.8949	13	30		5 | 5.5 | 5.0 | 4.5
	40	0.4488	26	0.5022	37	1.9912	145	0.8936	13	20		6 | 6.6 | 6.0 | 5.4
	50	0.4514	26	0.5059	36	1.9768	144	0.8923	13	10		7 | 7.7 | 7.0 | 6.3
27	0	0.4540		0.5095		1.9626	142	0.8910	13	0	63	8 | 8.8 | 8.0 | 7.2
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	′	°	9 | 9.9 | 9.0 | 8.1
												P. P.

° ′	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.		P. P.		
										44	43	42
27 0	0.4540		0.5095		1.9626		0.8910		0 63	1 4.4	4.3	4.2
10	0.4566	26	0.5132	37	1.9486	140	0.8897	13	50	2 8.8	8.6	8.4
20	0.4592	26	0.5169	37	1.9347	139	0.8884	13	40	3 13.2	12.9	12.6
30	0.4617	25	0.5206	37	1.9210	137	0.8870	14	30	4 17.6	17.2	16.8
40	0.4643	26	0.5243	37	1.9074	136	0.8857	13	20	5 22.0	21.5	21.0
50	0.4669	26	0.5280	37	1.8940	134	0.8843	14	10	6 26.4	25.8	25.2
28 0	0.4695	25	0.5317	37	1.8807	133	0.8829	14	0 62	7 30.8	30.1	29.4
10	0.4720	26	0.5354	38	1.8676	131	0.8816	13	50	8 35.2	34.4	33.6
20	0.4746	26	0.5392	38	1.8546	130	0.8802	14	40	9 39.6	38.7	37.8
30	0.4772	25	0.5430	37	1.8418	128	0.8788	14	30			
40	0.4797	26	0.5467	38	1.8291	127	0.8774	14	20		41	40	39
50	0.4823	25	0.5505	38	1.8165	126	0.8760	14	10	1 4.1	4.0	3.9
29 0	0.4848	26	0.5543	38	1.8040	125	0.8746	14	0 61	2 8.2	8.0	7.8
10	0.4874	25	0.5581	38	1.7917	123	0.8732	14	50	3 12.3	12.0	11.7
20	0.4899	25	0.5619	39	1.7796	121	0.8718	14	40	4 16.4	16.0	15.6
30	0.4924	26	0.5658	38	1.7675	121	0.8704	15	30	5 20.5	20.0	19.5
40	0.4950	25	0.5696	39	1.7556	119	0.8689	14	20	6 24.6	24.0	23.4
50	0.4975	25	0.5735	39	1.7437	119	0.8675	15	10	7 28.7	28.0	27.3
30 0	0.5000	25	0.5774	38	1.7321	116	0.8660	14	0 60	8 32.8	32.0	31.2
10	0.5025	25	0.5812	39	1.7205	116	0.8646	15	50	9 36.9	36.0	35.1
20	0.5050	25	0.5851	39	1.7090	115	0.8631	15	40		38	37
30	0.5075	25	0.5890	40	1.6977	113	0.8616	15	30	1	3.8	3.7
40	0.5100	25	0.5930	39	1.6864	113	0.8601	14	20	2	7.6	7.4
50	0.5125	25	0.5969	40	1.6753	111	0.8587	15	10	3	11.4	11.1
31 0	0.5150	25	0.6009	39	1.6643	110	0.8572	15	0 59	4	15.2	14.8
10	0.5175	25	0.6048	40	1.6534	109	0.8557	15	50	5	19.0	18.5
20	0.5200	25	0.6088	40	1.6426	108	0.8542	16	40	6	22.8	22.2
30	0.5225	25	0.6128	40	1.6319	107	0.8526	15	30	7	26.6	25.9
40	0.5250	25	0.6168	40	1.6212	107	0.8511	15	20	8	30.4	29.6
50	0.5275	24	0.6208	41	1.6107	105	0.8496	15	10	9	34.2	33.3
32 0	0.5299	25	0.6249	40	1.6003	104	0.8480	16	0 58		26	25	24
10	0.5324	24	0.6289	41	1.5900	103	0.8465	15	50	1	2.6	2.5	2.4
20	0.5348	25	0.6330	41	1.5798	102	0.8450	15	40	2	5.2	5.0	4.8
30	0.5373	25	0.6371	41	1.5697	101	0.8434	16	30	3	7.8	7.5	7.2
40	0.5398	24	0.6412	41	1.5597	100	0.8418	16	20	4	10.4	10.0	9.6
50	0.5422	24	0.6453	41	1.5497	100	0.8403	15	10	4	13.0	12.5	12.0
33 0	0.5446	25	0.6494	42	1.5399	98	0.8387	16	0 57	6	15.6	15.0	14.4
10	0.5471	24	0.6536	41	1.5301	98	0.8371	16	50	7	18.2	17.5	16.8
20	0.5495	24	0.6577	42	1.5204	97	0.8355	16	40	8	20.8	20.0	19.2
30	0.5519	24	0.6619	42	1.5108	96	0.8339	16	30	9	23.4	22.5	21.6
40	0.5544	25	0.6661	42	1.5013	95	0.8323	16	20		23	17	16
50	0.5568	24	0.6703	42	1.4919	94	0.8307	16	10	1	2.3	1.7	1.6
34 0	0.5592	24	0.6745	42	1.4826	93	0.8290	17	0 56	2	4.6	3.4	3.2
10	0.5616	24	0.6787	43	1.4733	93	0.8274	16	50	3	6.9	5.1	4.8
20	0.5640	24	0.6830	43	1.4641	92	0.8258	16	40	4	9.2	6.8	6.4
30	0.5664	24	0.6873	43	1.4550	91	0.8241	17	30	5	11.5	8.5	8.0
40	0.5688	24	0.6916	43	1.4460	90	0.8225	16	20	6	13.8	10.2	9.6
50	0.5712	24	0.6959	43	1.4370	90	0.8208	17	10	7	16.1	11.9	11.2
35 0	0.5736	24	0.7002	44	1.4281	89	0.8192	16	0 55	8	18.4	13.6	12.8
10	0.5760	24	0.7046	43	1.4193	88	0.8175	17	50	9	20.7	15.3	14.4
20	0.5783	23	0.7089	44	1.4106	87	0.8158	17	40		15	14	13
30	0.5807	24	0.7133	44	1.4019	87	0.8141	17	30	1	1.5	1.4	1.3
40	0.5831	24	0.7177	44	1.3934	85	0.8124	17	20	2	3.0	2.8	2.6
50	0.5854	23	0.7221	44	1.3848	86	0.8107	17	10	3	4.5	4.2	3.9
36 0	0.5878	24	0.7265	44	1.3764	84	0.8090	17	0 54	4	6.0	5.6	5.2
	Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	′ °	5	7.5	7.0	6.5
									P. P.	6	9.0	8.4	7.8
										7	10.5	9.8	9.1
										8	12.0	11.2	10.4
										9	13.5	12.6	11.7

°	′	Sin.	d.	Tan.	d.	Cot.	d.	Cos.	d.		
36	0	0.5878	23	0.7265	45	1.3764	84	0.8090	17	0	54
	10	0.5901	24	0.7310	45	1.3680	83	0.8073	17	50	
	20	0.5925	23	0.7355	45	1.3597	83	0.8056	17	40	
	30	0.5948	24	0.7400	45	1.3514	82	0.8039	18	30	
	40	0.5972	23	0.7445	45	1.3432	81	0.8021	17	20	
	50	0.5995	23	0.7490	46	1.3351	81	0.8004	18	10	
37	0	0.6018	23	0.7536	45	1.3270	80	0.7986	17	0	53
	10	0.6041	24	0.7581	46	1.3190	79	0.7969	18	50	
	20	0.6065	23	0.7627	46	1.3111	79	0.7951	17	40	
	30	0.6088	23	0.7673	47	1.3032	78	0.7934	18	30	
	40	0.6111	23	0.7720	46	1.2954	78	0.7916	18	20	
	50	0.6134	23	0.7766	47	1.2876	77	0.7898	18	10	
38	0	0.6157	23	0.7813	47	1.2799	76	0.7880	18	0	52
	10	0.6180	22	0.7860	47	1.2723	76	0.7862	18	50	
	20	0.6202	23	0.7907	47	1.2647	75	0.7844	18	40	
	30	0.6225	23	0.7954	48	1.2572	75	0.7826	18	30	
	40	0.6248	23	0.8002	48	1.2497	74	0.7808	18	20	
	50	0.6271	22	0.8050	48	1.2423	74	0.7790	19	10	
39	0	0.6293	23	0.8098	48	1.2349	73	0.7771	18	0	51
	10	0.6316	22	0.8146	49	1.2276	73	0.7753	18	50	
	20	0.6338	23	0.8195	48	1.2203	72	0.7735	19	40	
	30	0.6361	22	0.8243	49	1.2131	72	0.7716	18	30	
	40	0.6383	23	0.8292	50	1.2059	71	0.7698	19	20	
	50	0.6406	22	0.8342	49	1.1988	70	0.7679	19	10	
40	0	0.6428	22	0.8391	50	1.1918	71	0.7660	18	0	50
	10	0.6450	22	0.8441	50	1.1847	69	0.7642	19	50	
	20	0.6472	22	0.8491	50	1.1778	70	0.7623	19	40	
	30	0.6494	23	0.8541	50	1.1708	68	0.7604	19	30	
	40	0.6517	22	0.8591	51	1.1640	69	0.7585	19	20	
	50	0.6539	22	0.8642	51	1.1571	67	0.7566	19	10	
41	0	0.6561	22	0.8693	51	1.1504	68	0.7547	19	0	49
	10	0.6583	21	0.8744	52	1.1436	67	0.7528	19	50	
	20	0.6604	22	0.8796	51	1.1369	66	0.7509	19	40	
	30	0.6626	22	0.8847	52	1.1303	66	0.7490	20	30	
	40	0.6648	22	0.8899	53	1.1237	66	0.7470	19	20	
	50	0.6670	21	0.8952	52	1.1171	65	0.7451	20	10	
42	0	0.6691	22	0.9004	53	1.1106	65	0.7431	19	0	48
	10	0.6713	21	0.9057	53	1.1041	64	0.7412	20	50	
	20	0.6734	22	0.9110	53	1.0977	64	0.7392	19	40	
	30	0.6756	21	0.9163	54	1.0913	63	0.7373	20	30	
	40	0.6777	22	0.9217	54	1.0850	64	0.7353	20	20	
	50	0.6799	21	0.9271	54	1.0786	62	0.7333	19	10	
43	0	0.6820	21	0.9325	55	1.0724	63	0.7314	20	0	47
	10	0.6841	21	0.9380	55	1.0661	62	0.7294	20	50	
	20	0.6862	22	0.9435	55	1.0599	61	0.7274	20	40	
	30	0.6884	21	0.9490	55	1.0538	61	0.7254	20	30	
	40	0.6905	21	0.9545	56	1.0477	61	0.7234	20	20	
	50	0.6926	21	0.9601	56	1.0416	61	0.7214	21	10	
44	0	0.6947	20	0.9657	56	1.0355	60	0.7193	20	0	46
	10	0.6967	21	0.9713	57	1.0295	60	0.7173	20	50	
	20	0.6988	21	0.9770	57	1.0235	59	0.7153	20	40	
	30	0.7009	21	0.9827	57	1.0176	59	0.7133	21	30	
	40	0.7030	20	0.9884	58	1.0117	59	0.7112	20	20	
	50	0.7050	21	0.9942	58	1.0058	58	0.7092	21	10	
45	0	0.7071		1.0000		1.0000		0.7071		0	45
		Cos.	d.	Cot.	d.	Tan.	d.	Sin.	d.	′	°

P. P.				
	58	57	56	55
1	5.8	5.7	5.6	5.5
2	11.6	11.4	11.2	11.0
3	17.4	17.1	16.8	16.5
4	23.2	22.8	22.4	22.0
5	29.0	28.5	28.0	27.5
6	34.8	34.2	33.6	33.0
7	40.6	39.9	39.2	38.5
8	46.4	45.6	44.8	44.0
9	52.2	51.3	50.4	49.5
	54	53	52	51
1	5.4	5.3	5.2	5.1
2	10.8	10.6	10.4	10.2
3	16.2	15.9	15.6	15.3
4	21.6	21.2	20.8	20.4
5	27.0	26.5	26.0	25.5
6	32.4	31.8	31.2	30.6
7	37.8	37.1	36.4	35.7
8	43.2	42.4	41.6	40.8
9	48.6	47.7	46.8	45.9
	50	49	48	
1	5.0	4.9	4.8	
2	10.0	9.8	9.6	
3	15.0	14.7	14.4	
4	20.0	19.6	19.2	
5	25.0	24.5	24.0	
6	30.0	29.4	28.8	
7	35.0	34.3	33.6	
8	40.0	39.2	38.4	
9	45.0	44.1	43.2	
	47	46	45	
1	4.7	4.6	4.5	
2	9.4	9.2	9.0	
3	14.1	13.8	13.5	
4	18.8	18.4	18.0	
5	23.5	23.0	22.5	
6	28.2	27.6	27.0	
7	32.9	32.2	31.5	
8	37.6	36.8	36.0	
9	42.3	41.4	40.5	
	24	23	22	21
1	2.4	2.3	2.2	2.1
2	4.8	4.6	4.4	4.2
3	7.2	6.9	6.6	6.3
4	9.6	9.2	8.8	8.4
5	12.0	11.5	11.0	10.5
6	14.4	13.8	13.2	12.6
7	16.8	16.1	15.4	14.7
8	19.2	18.4	17.6	16.8
9	21.6	20.7	19.8	18.9
	20	19	18	17
1	2.0	1.9	1.8	1.7
2	4.0	3.8	3.6	3.4
3	6.0	5.7	5.4	5.1
4	8.0	7.6	7.2	6.8
5	10.0	9.5	9.0	8.5
6	12.0	11.4	10.8	10.2
7	14.0	13.3	12.6	11.9
8	16.0	15.2	14.4	13.6
9	18.0	17.1	16.2	15.3

P. P.

avoided, if possible, since the differences change very rapidly, and the computation is therefore likely to be inexact.

In finding the functions of an angle, note carefully whether the difference obtained from the table of proportional parts is to be added or subtracted, by observing whether the function is increasing or decreasing as the angle increases. For example, the sine of 21° is .3584, and the following sines, reading downwards, are .3611, .3638, etc. The sine of 21° 6′ is greater than that of 21°, and the difference for 6′ must be added. On the other hand, the cosine of 21° is .9336, and the following cosines, reading downwards, are .9325, .9315, etc.; that is, as the angle grows larger the cosine decreases, and the difference obtained for any angle between 21° and 21° 10′, say 21° 6′, must be subtracted from the cosine of 21°.

Suppose the function, i. e., the sine, cosine, tangent, or cotangent is given and the corresponding angle is to be found; for example, find the angle whose sine is .4943. First find in the second column the sine next *smaller* than .4943, which is .4924, and the difference for 10′ is 26. The angle corresponding to .4924 is 29° 30′. Subtracting the .4924 from .4943, the first remainder is 19; in the table of proportional parts under 26, the part next lower than this difference, is 18.2, opposite which is 7′. Subtracting 18.2 from 19 leaves .8 as the second remainder. In the table under 26 is found 7.8, which with its decimal point moved one place to the left is nearest to the second remainder, and opposite 7.8 is 3, which indicates .3′ or 18″. Hence, the angle is 29° 30′ + 7′ + 18″ = 29° 37′ 18″.

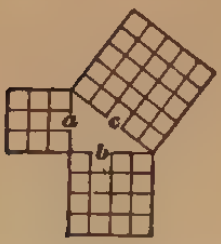
MENSURATION

In the following formulas, unless otherwise stated, the letters have the meanings here given:

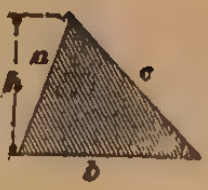
A = area of a plane figure;
d = diameter;
r = radius;
p = perimeter, or circumference;
π = ratio of any circumference to its diameter.

POLYGONS

Rectangle and parallelogram
$A = ab$

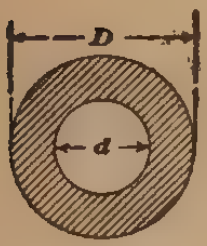


Right-angled triangle
$c^2 = a^2 + b^2$
$A = \frac{1}{2}\, ab$



Any triangle
$A = \frac{1}{2}\, bh$

CIRCLES



The circle: $p = \pi d = 2\pi r$

$$A = \pi r^2 = \frac{\pi d^2}{4}$$

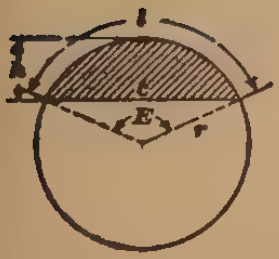
The ring: $A = \frac{\pi}{4}(D^2 - d^2)$

The sector:

$$A = \tfrac{1}{2}lr = \frac{E}{360}\pi r^2 = .008727 r^2 E$$

E = angle; l = length of arc

The segment:



$$A = \tfrac{1}{2}[lr - c(r-h)] = \frac{E}{360}\pi r^2 - \frac{c}{2}(r-h)$$

$$l = \frac{\pi r E}{180} = .0175 r E$$

$$c = \text{chord} = 2\sqrt{2hr - h^2}$$

ELLIPSE

$$p = \pi \sqrt{\frac{D^2 + d^2}{2} - \frac{(D-d)^2}{8.8}}$$

$$A = \frac{\pi}{4} Dd$$

SOLIDS

The cylinder: Convex surface $= \pi dh$

Both end surfaces $= \frac{\pi d^2}{2}$

Volume $= \frac{\pi d^2}{4} h$

The sphere:

$$\text{Surface} = \pi d^2 = 4\pi r^2$$

$$\text{Volume} = \frac{1}{6}\pi d^3 = \frac{4}{3}\pi r^3$$

USEFUL NUMBERS

$\frac{1}{\pi} = .3183$ $\quad \pi^2 = 9.8696$ $\quad \frac{1}{\pi^2} = .1013$

$\sqrt{\pi} = 1.7725$ $\quad \frac{1}{\sqrt{\pi}} = .5642$

MECHANICS

FALLING BODIES

Let $g = 32.16$ = constant acceleration due to the attraction of the earth;

t = number of seconds that the body falls;

v = velocity in feet per second at the end of the time t;

h = distance, in feet, that the body falls during the time t.

Then,
$$v = gt = \frac{2h}{t} = \sqrt{2gh} = 8.02\sqrt{h};$$

$$h = \frac{vt}{2} = \frac{gt^2}{2} = \frac{v^2}{2g} = .015547v^2;$$

$$t = \frac{v}{g} = \frac{2h}{v} = \sqrt{\frac{2h}{g}} = .24938\sqrt{h}.$$

If h is in centimeters and v in centimeters per second, then $t = 981$ at Paris.

CENTRIFUGAL FORCE

F = centrifugal force, in pounds;

W = weight of revolving body, in pounds;

m = mass of body $= \frac{W}{g}$;

r = distance from axis of motion to center of gravity of body, in feet;

N = number of revolutions per minute;
v = velocity, in feet per second.

$$F = \frac{Wv^2}{gr} = \frac{Mv^2}{r} = .00034WrN^2.$$

In calculating the centrifugal force of flywheels, it is customary to neglect the arms and take r equal to the mean radius of the rim; in such cases, W is taken as one-half the weight of the rim. The result thus obtained, divided by π, is approximately the force tending to burst the flywheel rim.

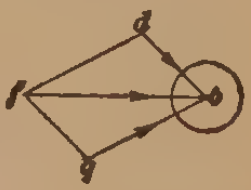
EXAMPLE.—What is the force tending to burst a flywheel rim weighing 7 tons, making 150 rev. per min., and having a mean radius of 5 ft.?

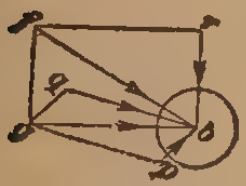
SOLUTION.—

$$F = \frac{.00034 \times (\frac{1}{2} \times 7 \times 2{,}000) 5 \times 150^2}{3.1416} = 85{,}227 \text{ lb.}$$

PARALLELOGRAM OF FORCES

Let db and qb represent the magnitudes and directions of two forces that act to move the body b. By completing the parallelogram, there will be obtained a diagonal force fb, whose magnitude and direction are equal to the effect produced by db and qb. fb is called the resultant of db and qb. If three or more forces act in different directions to move a body b, find the resultant of any two of them, and consider it as a single force. Between this and the next force find a second resultant. Thus, pb, qb, and rb are magnitudes and directions of the forces. $pb + qb + rb = gb + rb = fb$, which is the resultant in the magnitude and direction of the three forces pb, qb, and rb.





WORK AND POWER

Work is the overcoming of resistance through a distance. The unit of work is the *foot-pound;* that is, it equals 1 lb. raised vertically 1 ft. The amount of work done is equal to

the resistance in pounds multiplied by the distance in feet through which it is overcome. If a body is lifted, the resistance is the weight or the overcoming of the attraction of gravity, the work done being the weight in pounds multiplied by the height of the lift in feet. If a body moves in a horizontal direction, the work done is the friction overcome, or the force needed to move a resistant body or combination of bodies, multiplied by the distance moved through.

Power is the rate of doing work, or the quantity of work done in unit time. The ordinary unit of mechanical power is the horsepower, which is equivalent to 33,000 ft.-lb. per min., or 550 ft.-lb. per sec.

The work necessary to be done in raising a body weighing W lb. through a height of h ft. equals $W\,h$ ft.-lb. The total work that any moving body is capable of doing in being brought to rest equals its kinetic energy, or $\frac{Wv^2}{2g} = \frac{1}{2}\,mv^2$.

The kinetic energy of a 200,000-lb. train running at 40 mi. per hr. (58.7 ft. per sec.) is $200{,}000 \times 58.7^2 \div (2 \times 32.16) = 10{,}714{,}220$ ft.-lb.; the retarding force necessary to stop the train within 2,000 ft. is $10{,}714{,}220 \div 2{,}000 = 5357.1$ lb., and the average power required to stop the train in $\frac{1}{2}$ min. is $10{,}714{,}220 \div \frac{1}{2} = 21{,}428{,}440$ ft.-lb. per min. or $21{,}428{,}440 \div 33{,}000 = 649.3$ H. P.

BELTS

To find the angle of contact of a belt on each pulley:

Let D = diameter of the larger pulley, in inches;
d = diameter of the smaller pulley, in inches;
l = distance between the pulley centers, in inches:
a = $\frac{1}{2}$ the arc of contact on the smaller pulley.

Then, $$\text{Cos } a = \frac{D - d}{2\,l}.$$

From a table of natural cosines the angle a can be found and $2\,a$ = the arc of contact on the smaller pulley; $360° - 2a$ = the arc of contact on the larger pulley. In calculating belts, only the arc of contact on the smaller pulley need be considered.

To find the length L of a belt,

$$L = \frac{D+d}{2} \times 3\tfrac{1}{2} + 2l, \text{ approximately.}$$

NOTE.—These formulas apply only to ordinary open belts and not to crossed belts.

EXAMPLE.—A 12-in. pulley and a 60-in. pulley with centers 15 ft. apart are connected by an open belt. (*a*) Find the arc of contact of the belt on each pulley. (*b*) Find the length of the belt.

SOLUTION.—(*a*) 15 ft. = 180 in. $(60 - 12) \div (2 \times 180) = .1333 = \cos 82° 20'$.

Arc of contact on smaller pulley $= 2 \times 82° 20' = 164° 40'$.

Arc of contact on larger pulley $= 360 - 164° 40' = 195° 20'$.

(*b*) $\frac{60+12}{2} \times 3\frac{1}{2} + 2 \times 180 = 477$ in. $= 39$ ft. 9 in.

The following formulas give conservative results:

Let C = allowable effective pull, in pounds per inch, width of belt (see table);

H = horsepower to be transmitted;

W = width of belt, in inches;

V = belt speed, in feet per minute.

Then, $W = \frac{33{,}000H}{VC}$; $H = \frac{VCW}{33{,}000}$

ALLOWABLE BELT PULL

Arc Covered by Belt		Allowable Pull per Inch Width in Pounds	
Degrees	Fraction of Circumference	Single belt	Double belt
90	.250	23	32.9
112½	.312	27.4	39.2
120	.333	28.8	41.2
135	.375	31.3	44.7
150	.417	33.8	48.3
157½	.437	34.9	49.9
180	.500	38.1	54.5

Single belting is $\frac{3}{16}$ in. thick; four-ply cotton belting is generally considered equivalent to single belting. To install one pulley directly over the other, so that the belt runs vertical should be avoided if possible; it is better that the angle between the belt and the floor does not exceed 45°, and the bottom side of the belt should be the driving side. The distance between pulley centers depends on the size of the pulleys and of the belt; it should be great enough so that the belt will run with a slight sag and a gently undulating motion, but not great enough to cause excessive sag and an unsteady flapping motion of the belt. In general, the centers of small pulleys carrying light narrow belts should be about 15 ft. apart and the belt sag 1½ to 2 in.; for large pulleys and heavy belts the distance should be 20 to 30 ft. and the sag 2½ to 5 in.

Loose-running belts will last much longer than tight ones, and will be less likely to cause heating and wear of pulley bearings. High-speed belts are less likely to slip than low-speed belts; hence, pulleys should be selected so as to make the belt speeds high, provided they do not exceed 3,500 ft. per min. for laced belts and 5,000 ft. per min. for endless belts. Leather belts should be run with the grain, or hair, side next to the pulley; they should be kept clean, dry, and free from grease and lubricating oil. A dry, husky, leather belt can be made soft and pliable by the application of a coat of melted tallow and beeswax; this should be done only when the belt becomes dry and hard.

ELECTRICITY AND MAGNETISM

ELECTRICAL UNITS, SYMBOLS, AND QUANTITIES

The fundamental units, from which are derived the units used in electricity and magnetism, are the *centimeter* as the unit of length, the *gram* as the unit of mass, and the *second* as the unit of time. A system of units derived from these fundamental units is called the *centimeter-gram-second* or *C. G. S., system.* The C. G. S. unit of velocity, sometimes called the *kine* is 1 centimeter per second; the C. G. S. unit of force, called the *dyne*, is the force required to produce an acceleration of 1 kine per second in a body having a mass of 1 gram; the C. G. S. unit of work or energy, called the *erg*, is the work done by a force of 1 dyne working through a distance of 1 centimeter.

Two systems of units are derived from the fundamental units: the *electrostatic units*, based on the force exerted between two quantities of electricity; and the *electromagnetic units*, based on the force exerted between two magnetic poles or between a current and a magnetic pole. The ratio of the electrostatic to the electromagnetic units is some multiple or submultiple of the velocity v of light in air, which is 3×10^{10} cm. per sec.

The electrostatic units are those of quantity, current, electromotive force, resistance, capacity, and inductivity. These units have not been named.

The electromagnetic units may be considered in two classes, electric units and magnetic units. The C. G. S. electromagnetic units have not been named and, as they are inconvenient in magnitude for practical purposes, a so-called practical system of units has been adopted. Practical electromagnetic units are equal to the C. G. S. electromagnetic units multiplied or divided by some power of 10. The practical units are used to express quantity of electricity, strength of electric current, electromotive force, resistance, work, power, inductance, and capacity.

The magnetic units that would correspond to the practical electric units are not used and have not been definitely named on account of their inconvenient magnitudes. The names of all the practical electromagnetic units, except the mho, have been adopted by some international conventions and their use legalized by most of the important nations.

Numerical Expression of Electrical Units.—The expression of electrical units often requires large numbers, and it is customary to use the multiple 10 with an index to indicate the power to which it is raised. The sign of the index indicates whether the designated power of 10 is to be used as a multiplier or as a divisor. For example, $7\times10^{2}=700$, but $7\times10^{-2}=.07$; $v\times10^{-1}=\frac{v}{10}$; $v^{2}\times10^{-9}=\frac{v^{2}}{1{,}000{,}000{,}000}$ $723\times10^{-4}=\frac{723}{10{,}000}=.0723$; etc.

LIST OF IMPORTANT SYMBOLS

In the two tables following, l represents a length or distance, F a force, v a velocity, T the number of turns in a coil or circuit, t time, W work, and A an area.

In this work, the following meanings will be understood unless otherwise specified:

A = area in square centimeters;
$\mathbf{A}$ = area in square inches;
$\mathfrak{B}$ = magnetic density per square centimeter;
$\mathbf{B}$ = magnetic density per square inch;
C = capacity in farads or microfarads;
D, d = diameters;
E, e = electromotive force, in volts;
F = force, usually in dynes;
$\mathfrak{F}$ = magnetomotive force;
G = conductance;
$\mathfrak{H}$ = intensity of magnetic field per square centimeter;
$\mathbf{H}$ = intensity of magnetic field per square inch;
H. P. = horsepower;
I = current, in amperes;
$\mathfrak{J}$ = intensity of magnetization;
J = work, in joules;

MAGNETIC UNITS

Magnetic Quantities	Symbol	Defining Equation	Names of C. G. S. Units
Strength of pole	m	$m = \sqrt{Fl^2}$	Has no name
Magnetic moment	$\mathfrak{M}$	$\mathfrak{M} = ml$	Has no name
Intensity of magnetization	$\mathfrak{I}$	$\mathfrak{I} = \frac{m}{A}$	Has no name
Magnetizing force or field density	$\mathfrak{H}$	$\mathfrak{H} = \frac{F}{m} = \frac{m}{l^2}$	Gauss, or 1 line of force per sq. cm.
Susceptibility	κ	$\kappa = \frac{\mathfrak{I}}{\mathfrak{H}}$	Has no name
Magnetomotive force	$\mathfrak{F}$	$\mathfrak{F} = \mathfrak{H}l$ or $\mathfrak{F} = \frac{W}{m}$	Gilbert (Not internationally accepted)
Magnetic density or magnetic induction	$\mathfrak{B}$	$\mathfrak{B} = 4\pi\mathfrak{I} + \mathfrak{H}$	Gauss, or 1 line of force per sq. cm.
Magnetic flux	Φ	$\Phi = \mathfrak{B}A$	Maxwell, or 1 line of force
Permeability	μ	$\mu = \frac{\mathfrak{B}}{\mathfrak{H}}$	Has no name
Reluctance	$\mathfrak{R}$	$\mathfrak{R} = \frac{\mathfrak{F}}{\Phi}$ or $\mathfrak{R} = \frac{l}{A\mu}$	Oersted (Not internationally accepted)

Electrical Quantities	Symbol	Defining Equation	Names of Practical Electromagnetic Units	Quantities by Which to Multiply Practical Electromagnetic Units to Reduce to	
				C. G. S. Electromagnetic Units	C. G. S. Electrostatic Units $v=3\times10^{10}$
Current.....	I or i	$I=\frac{F}{l\mathcal{H}}$	Ampere	10^{-1}	$v\times10^{-1}=3\times10^{9}$
Quantity of electricity...	Q or q	$Q=It$ or $Q=\sqrt{Fl^2}$	Coulomb	10^{-1}	$v\times10^{-1}=3\times10^{9}$
Electromotive force.....	E or e	$E=\mathcal{H}lv=\frac{\Phi}{t}$ or $E=\frac{W}{Q}$	Volt	10^{8}	$10^{8}\div v=\frac{1}{3}\times10^{-2}$
Resistance....	R	$R=\frac{E}{I}$ or $R=\frac{W}{I^2t}$	Ohm	10^{9}	$10^{9}\div v^2=\frac{1}{9}\times10^{-11}$
Resistivity....	ρ	$\rho=\frac{RA}{l}$	Ohm		

Electrical Quantities	Symbol	Defining Equation	Names of Practical Electromagnetic Units	Quantities by Which to Multiply Practical Electromagnetic Units to Reduce to	
				C. G. S. Electromagnetic Units	C. G. S. Electrostatic Units $v=3\times10^{10}$
Conductance...	G	$G=\frac{1}{R}$	Mho (Not internationally accepted)		
Conductivity..	γ	$\gamma=\frac{1}{\rho}$	Mho (Not internationally accepted)		
Work or energy	W or J	$J=EIt$	Joule	10^7 ergs	
Power.....	P	$P=EI$	Watt	10^7 ergs per sec.	
Capacity.....	C	$C=\frac{Q}{E}$	Farad	10^{-9}	$v^2\times10^{-9}=9\times10^{11}$
Inductivity....	K	$K=\frac{Q}{Q'}$ (air as dielectric) (other dielectric) or $K=\frac{4\pi Cl}{A}$	A number		
Inductance (self).....	L	$L=\frac{\Phi T}{I}$	Henry	10^9	$10^9\div v^2=\frac{1}{9}\times10^{-11}$
Inductance (mutual)....	M	$M=\frac{\Phi T}{I}$	Henry	10^9	$10^9\div v^2=\frac{1}{9}\times10^{-11}$

K. W. = power, in kilowatts;
l = length, in centimeters;
l = length, in inches;
L = inductance or coefficient of self-induction, in henrys;
$\mathfrak{M}$ = magnetic moment;
M = mutual inductance;
m = strength of pole;
P = power, in watts;
Q = quantity of electricity, in coulombs;
$\mathfrak{R}$ = reluctance;
R = resistance, in ohms;
ρ = resistivity;
t = time, in seconds;
v = volume, in cubic centimeters, or velocity, in centimeters per second;
V = volume, in cubic inches;
W = work;
Φ = total magnetic flux;
μ = permeability.

PRACTICAL ELECTROMAGNETIC UNITS

Current (I).—The strength of current I is the rate at which electricity is flowing through a conductor, and is analogous to the rate of flow of water through a pipe in gallons per second.

The unit strength of current, called the *ampere*, is represented sufficiently well for practical use by the unvarying current that, when passed through a specified solution of nitrate of silver in water, deposits silver at the rate of .001118 gram per sec.

A *milliampere* is equal to $\frac{1}{1{,}000}$ or .001 ampere.

Quantity of Electricity (Q).—The quantity of electricity that passes through a circuit is comparable to the quantity of water that flows through a pipe, and equals the product of the rate of flow and the time; that is,

$$Q = It$$

If I is 1 ampere and t is 1 second, Q is 1 *coulomb*, which is the practical unit quantity of electricity. If 5 amperes is flowing through a wire, then, in 30 seconds, $5 \times 30 = 150$ coulombs of electricity will pass. One coulomb will deposit

.001118 gram of silver out of a neutral solution of silver nitrate consisting of 15 parts by weight of silver nitrate and 85 parts of water.

Electromotive Force (*E. M. F.*, or *E*).—Electromotive force, or electric pressure, is that which causes electricity to flow in a closed circuit. The practical unit of E. M. F. is the *volt*, which is the E. M. F. that will cause a current of 1 ampere to flow through a resistance of 1 ohm. The volt is represented sufficiently well for practical use by $\frac{1000}{1434}$ of the E. M. F. between the electrodes of a Carhart-Clarke standard cell at a temperature of 15° C. A *kilovolt* = 1,000 volts, a *millivolt* = .001 volt, and a *microvolt* = .000001 volt.

Resistance (*R.*)—All substances offer resistance to the passage of electricity through them, the amount of the resistance depending on the substance and on its shape; that is, on the length and cross-section. The resistance of all metals increases with an increase in the temperature; while the resistance of carbon, insulating materials, and electrolytic solutions decreases with an increase in their temperatures.

The practical *unit of resistance* is the *ohm*. A conductor has a resistance of 1 ohm when the pressure required to send 1 ampere through it is 1 volt. In other words, the drop, or fall, in pressure through a resistance of 1 ohm, when a current of 1 ampere is flowing, is 1 volt. The *microhm* = .000001 ohm. The *megohm* = 1,000,000 ohms. The ohm is one of the few electrical units for which a material standard can be used. Different standards have been used, all based on the resistance of a column of mercury at 0° C., having a cross-sectional area of 1 sq. mm. and a different length for each standard, as follows:

1. The *international ohm*, now universally recognized as the standard, has a column of mercury 106.3 cm. in length.
2. The *legal ohm*, in use previous to 1893, but now superseded by the international ohm, has a column of mercury 106 cm. in length.
3. The *British Association unit* (B. A. U.). which preceded the legal ohm but which is no longer in use, has a column of mercury 104.8 cm. in length.

RESISTANCES AND TEMPERATURE COEFFICIENTS OF METALS*

Metal	Specific Resistance ρ† (Microhms per Centimeter Cube) — At 0° C. or 32° F.	Resistance of 1 Mil-Foot in Ohms — 0° C. or 32° F.	Resistance of 1 Mil-Foot in Ohms — 23.8° C. or 75° F.	Temperature Coefficient per Degree C. Between 0° and 100° C.	Temperature Coefficient per Degree F. Between 32° and 212° F.	Percentage Conductivity	Relative Resistance
Silver,[2] pure annealed..	1.468	8.831	9.674	.004000	.002220	108.60	.925
Copper,[2] pure annealed.	1.561	9.390		.004280	.002380	102.10	.980
Copper,[1] annealed	1.594	9.590	10.505	.004020	.002230	100.00	1.000
Silver, hard-drawn.....	1.629	9.799				97.80	1.022
Copper,[1] hard-drawn...	1.631	9.810	10.745	.004020	.002230	97.80	1.022
Gold[2] (99.9% pure)....	2.197	13.216		.003770	.002090	72.55	1.378
Aluminum (99.5% pure)	2.530	15.219				63.00	1.587
Aluminum[2] (commercial—97.5% pure)...	2.665	16.031		.004350	.002420	59.80	1.672
Magnesium[2].....	4.355	26.197		.003810	.002120	36.60	2.732
Zinc[2] (very pure).....	5.751	34.595		.004060	.002260	27.72	3.608
Iron,[2] approximately pure.....	9.065	54.529		.006250	.003470	17.50	5.714
Iron "E. B. B." iron wire	9.759	58.702	65.190	.004630	.002570	16.20	6.173

Cadmium[2] (pure).....	10.023	60.292		.004190	.002320	15.90	6.289
Palladium[2] (pure).....	10.219	61.471		.003540	.001970	15.60	6.410
Platinum[2] (pure)	10.917	65.670		.003669	.002038	14.60	6.845
Iron, "B. B." iron wire	11.085	68.680	76.270	.004630	.002570	13.50	7.407
Nickel[2].....	12.323	74.128		.006220	.003460	12.94	7.726
Tin[2] (pure).....	13.048	78.489		.004400	.002450	12.22	8.184
Steel (wire).....	13.495	81.179	90.150	.004630	.002570	11.60	8.621
Thallium[2] (pure).....	17.633	106.070		.003980	.002210	9.04	11.060
Lead[2] (pure).....	20.380	122.590	134.610	.004110	.002280	7.82	12.790
Antimony (pressed)....	35.400	212.950		.004100		4.50	22.220
Mercury[2] (pure).....	94.070	565.870	610.370	.000720	.000400	1.69	59.170
Bismuth (pressed).....	130.800	786.810		.003540		1.22	81.970

*The resistances are given in international ohms and 1 sq. cm. in sectional area, at 0° C., in microhms. †This is the resistance of a piece 1 cm. long and 1 sq. cm. in sectional area, at 0° C., in microhms. [1]Determined by Matthiessen and taken as the standard. [2]Determined by Fleming and Dewar. According to the American Institute of Electrical Engineers, the temperature coefficient of pure commercial copper should be .0042 per degree C

RESISTANCES AND TEMPERATURE COEFFICIENTS OF ALLOYS†

Substance	Specific Resistance ρ‡ (Microhms per Centimeter Cube) At 0° C. or 32° F.	Resistance of 1 Mil-Foot in Ohms at 0° C. or 32° F.	Temperature Coefficient per Degree Centigrade	Temperature Coefficient per Degree Fahrenheit	Percentage Conductivity	Relative Resistance
Brass	7.200	43.310			22.15	4.515
Phosphor-bronze, commercial—*Cu*, *Sn*, *P*	8.479	51.005	.000640	.000356	18.80	5.319
Aluminum bronze	12.300	73.989	.001000	.000556	12.96	7.714
Platinum rhodium,[2] *Pt* 90, *Rh* 10	21.142	127.180	.001430*	.000795*	7.54	13.260
German silver,[3] *Cu* 50, *Zn* 35, *Ni* 15	21.250	127.800	.000400	.000220	7.50	17.300
Platinum silver,[3] *Pt* 66⅔, *Ag* 33⅓	24.900	149.800	.000310	.000170	6.40	15.600
German silver,[2] *Cu* 60, *Zn* 25, *Ni* 15	29.982	180.350	.000273*	.000152*	5.32	18.800
Platinum iridium,[2] *Pt* 80, *Ir* 20	30.896	185.850	.000822*	.000457*	5.16	19.380

Platinum silver,[2] *Pt* 33⅓, *Ag* 66⅔	31.582	189.980	.000243*	.000135*	5.05	19.800
Platinoid,[2] *Cu* 59, *Zn* 25.5, *Ni* 14, *W* (tungsten) 1.5	41.731	251.030	.000310*	.000172*	3.82	26.180
German silver,[3] *Cu* 55, *Zn* 20, *Ni* 35	45.540	271.100	.000330	.000180	3.50	28.600
Manganin,[2] *Cu* 84, *Ni* 4, *Mn* 12	46.678	280.790	.000000*		3.41	29.330
Constantan, *Cu* 58, *Ni* 41, *Mn* 1	50 52	300.77 312.80	±.000010	.000005	3.19 3.07	31.35 32.57
Reostene	76.468	459.990	.001100*	.000610*	2.08	48.080
Gray cast iron, *C* 3.46; graphite, 2.06; *Mn* .173; *S* .042; *Si* 2.04; *P* .151	114.000	684.000				
Carbon, arc light	4400 8600	26500 51700	.000520*	.000289*	.0360 .0186	2778 5376

*These are the temperature coefficients at 15° C. or 59° F.; the others are mean temperature coefficients between the freezing and boiling temperatures of water. †Where the proportions are not given, the experimenters merely stated that they were made of the usual proportions. As this is not very definite, we cannot give the proportions. ‡This is the resistance of a piece 1 cm. long and 1 sq. cm. in sectional area at 0° C. in microhms. [2]Determined by Fleming and Dewar. [3]Given by Jackson. *Pt* = platinum; *Ag* = silver; etc.

SIZE AND WEIGHT OF ANNEALED COPPER WIRE

(B. & S. Gauge, Specific Gravity, 8.89)

B. & S. Gauge	Diameter in Mils d †	Area in Circular Mils d^2 †	Area in Sq. In. $\frac{d^2 \times .7854}{1{,}000{,}000}$ *	Pounds per 1,000 Feet †	Pounds per Mile *	Feet per Pound †
0000	460.00	211,600	.16619	640.5	3,381.4	1.561
000	409.64	167,805	.13179	508.0	2 682.2	1.969
00	364.80	133,079	.10452	402.8	2.126.8	2.482
0	324.86	105,534	.082887	319.5	1,686.9	3.130
1	289.30	83,694	.065732	253.3	1,337.2	3.947
2	257.63	66,373	.052128	200.9	1,060.6	4.977
3	229.42	52,634	.041339	159.3	841.09	6.276
4	204.31	41,742	.032784	126.4	667.39	7.914
5	181.94	33,102	.025999	100.2	529.06	9.980
6	162.02	26,250	.020618	79.46	419.55	12.58
7	144.28	20,816	.016351	63.02	332.75	15.87
8	128.49	16.509	.012967	49.98	263.89	20.01
9	114.43	13 094	.010283	39.63	209.24	25.23
10	101.89	10,381	.0081548	31.43	165.95	31.82
11	90.742	8.234.0	.0064656	24.93	131.63	40.12
12	80.808	6,529.9	.0051287	19.77	104.39	50.59
13	71.961	5,178.4	.0040672	15.68	82.791	63.79
14	64.084	4,106.8	.0032254	12.43	76.191	80.44
15	57.068	3,256.7	.0025579	9.858	52.050	101.4

16	50.820	2,582.9	.0020285	7.818	41.277	127.9
17	45.257	2,048.2	.0016087	6.200	32.736	161.3
18	40.303	1,624.3	.0012757	4.917	25.960	203.4
19	35.890	1,288.1	.0010117	3.899	20.595	256.5
20	31.961	1,021.5	.0008023	3.092	16.324	323.4
21	28.462	810.10	.0006362	2.452	12.946	407.8
22	25.347	642.40	.0005045	1.945	10.268	514.2
23	22.571	509.45	.0004001	1.542	8.142	684.4
24	20.100	404.01	.0003173	1.223	6.457	817.6
25	17.900	320.40	.0002516	.9699	5.121	1020
26	15.940	254.10	.0001995	.7692	4.061	1300
27	14.195	201.50	.0001582	.6100	3.221	1639
28	12.641	159.79	.0001255	.4837	2.554	2067
29	11.257	126.72	.0000995	.3836	2.025	2607
30	10.025	100.50	.0000789	.3042	1.60€	3287
31	8.928	79.70	.0000625	.2413	1.274	4145
32	7.950	63.21	.0000496	.1913	1.010	5227
33	7.080	50.13	.0000393	.1517	.801	6591
34	6.305	39.75	.0000312	.1203	.635	8311
35	5.615	31.52	.0000247	.09543	.504	10480
36	5.000	25.00	.0000196	.07568	.400	13210
37	4.453	19.82	.0000155	.06001	.317	16660
38	3.965	15.72	.0000123	.04759	.251	21010
39	3.531	12.47	.0000097	.03774	.199	26500
40	3.145	9.89	.0000077	.02993	.158	33410

Material	Specific Resistance at 0° C. (Microhms per Cent. Cube)	Microhms per Cubic Inch at 0° C.	Resistance of Wire 1 Ft. Long and .001 In. Dia. Ohms at 0° C.	Per Cent. Increase of Resistance per Deg. Cent.	Melting Point Deg. Cent.	Specific Heat Mean	Ultimate Tensile Strength. Pounds per Square Inch	Specific Gravity	Weight of 1 Cu. In. Pound
Aluminum (Neuhausen), 99% *Al.* Dewar and Fleming	2.56	1.01	15.4	.423	600	.21		2.6	.094
Aluminum (commercial), 97.5% *Al.* Dewar and Fleming	2.67	1.05	16.0	.435	600	.21		2.6	.094
Aluminum (annealed). Matthiessen	2.89	1.14	17.4	.139	600	.21		2.6	.094
Aluminum, 94%; copper, 6%. Dewar and Fleming	2.90	1.14	17.4	.381					
Aluminum, 94%; copper, 6% (annealed). Charpentier	3.11	1.23	18.7					2.95	.107
Aluminum, 94%; copper, 6% (hard). Charpentier	3.33	1.31	20.0					2.95	.107
Aluminum, 94%; silver, 6%. Dewar and Fleming	4.64	1.83	27.8	.238					

Aluminum Bronze, *Cu* (90%) *Al* (10%). C. Limb.....	12.6	4.96	75.5	.105				7.7	.278
Antimony (compressed). Matthiessen.....	35.2	13.9	211	.389	440	.049		6.7	.242
Bessemer soft steel, *C* (.045); *Mn* (.200); *S* (.030); *Sl* (0); *P* (.040). Hopkinson	10.5	4.14	63.0	.		.117		7.8	.282
Bismuth (compressed). Matthiessen.....	130	51.2	780	.354	260	.030		9.8	.354
Cadmium (pure). Dewar and Fleming.....	10.0	3.93	60.0	.419				8.60	.310
Chrome bronze, copper, tin, and chromium. Hospitalier	1.64	.645	9.84				64,000	8.9	.321
Chrome bronze, copper, tin, and chromium.....	4.71	1.85	28.3				107,000		
Chrome bronze, copper, tin, and chromium. Hospitalier	7.80	3.07	46.8				150,000	8.9	.321
Chrome steel (annealed), *C*, 687; *Mn*, .28; *S*, .02; *Sl*, .134; *P*, .043; *Cr*, 1.195. Hopkinson.....	17.9	7.05	108						
Chrome steel (annealed), *C*, .532; *Mn*, .393; *S*, .02; *Sl*, .22; *P*, .04; *Cr*, .621. Hopkinson.....	19.4	7.65	117						
Electrolytic copper (annealed). Lagarde.....	1.54	.605	9.25	.445	1050	.093		9.05	.327
Electrolytic copper (annealed). Dewar and Fleming.....	1.56	.614	9.35	.428	1050	.093		8.91	.322
Copper (annealed). Matthiessen.....	1.59	.625	9.54	.388	1050	.093		8.9	.321

Copper, 50%; silver, 50% Abbott	1.84	.725	11.1						
Copper, 96%; silicon, 4% Abbott	2.11	.830	12.7						
Copper, 88%; silicon, 12% Abbott	2.94	1.16	17.7						
Copper, 99.29%; zinc, 71% R. Haas	1.83	.720	11.0	.373					
Copper, 90.9%; zinc, 9.1% R. Haas	3.64	1.43	21.8	.204					
Zinc, 99.5%; copper, 5% R. Haas	5.88	2.31	35.3	.385		.095		7.1	.256
Copper, 65.8%; zinc, 34.2% R. Haas	6.30	2.48	37.8	.158					
Cast copper	4.65	1.83	27.9						
Copper, 90%; lead, 10% Abbott	5.28	2.08	31.7						
Copper, 97%; aluminum, 3%. Dewar and Fleming	8.84	3.48	53.0	.090					
Copper, 87%; *Ni*, 6.5%; *Al*, 6.5%. Dewar and Fleming	14.9	5.87	89.5	.0645					
Copper, 90%; arsenic, 10% Abbott	17.6	6.94	106						
Copper, 75%; nickel, 25% Feussner and Lindeck	34.2	13.5	205	.019					
German silver. *Cu* (60); *Zn* (25); *Ni* (15). Feussner and Lindeck	30.0	11.8	180	.036					
Gold (annealed), Matthiessen	2.04	.803	12.3	.365	1100	.032		19.3	.695

Gold, 99.9% (pure). Dewar and Fleming	2.20	.865	13.2	.377	1200	.032		19.3	.695
Gold, 90%; silver, 10%. Dewar and Fleming	6.28	2.47	37.7	.124					
Gold, 67%; silver, 33% (alloy). Matthiessen	10.8	4.25	64.8	.065					
Iron (very pure). Dewar and Fleming	9.07	3.57	54.5	.625		.113		7.8	.282
Iron with .25% *Mn* and .01% *S*. Dewar and Fleming	10.5	4.14	63.0	.544		.113		7.8	.282
White cast iron, *C*, 2.04; graphite, *O*, *Mn*, .386; *S*, .467; *Si*, .764; *P*, .458. Hopkinson	56.6	22.3	340		1130			7.20	.260
Spiegeleisen—*C*, 4.5%; *Mn*, 7.97%; *S* traces, *Si*, .502% *P*, .128%. Hopkinson	105	41.4	630						
Grey cast iron—*C*, 3.46; graphite, 2.06; *Mn*, .173; *S*, .042; *Si*, 2.04; *P*, .151. Hopkinson	114	44.9	684		1220			7.20	.260
Wrought iron (annealed). Hopkinson	13.8	5.44	82.8					7.8	.282
Lead (compressed) Matthiessen	19.5	7.68	117	.387	330	.032		11.4	.410
Lead (pure). Dewar and Fleming	20.4	8.04	123	.411	330	.032		11.4	.410
Magnesium. Dewar and Fleming	4.36	1.72	26.2	.381		.25		1.74	.063
Manganese steel (annealed), *C*, .674; *Mn*, 4.73; *S*, .023; *Si*, .608; *P*, .078. Hopkinson	39.3	15.5	236		1260			7.8	.282

Copper, 84%; manganese, 12%; *Ni*, 4% (manganine). Dewar and Fleming	46.7	18.4	281	.00				8.9	.321
Copper, 73%; manganese, 24%; nickel, 3%. Feussner and Lindeck	47.7	18.8	287	.003				8.9	.321
Copper, 80.5%; manganese, 16.5%; nickel, 3% (manganine). Tests by G. E.Co.	49.0	19.3	294	.0				8.9	.321
Copper, 83.4%; *Mn*, 15.2%; *Fe*, 1.4%. Tests by G. E. Co	50.0	19.7	300	.0				8.9	.321
Copper, 79.5%; *Mn*, 19.7%; *Fe*, .8%. Tests by G. E. Co	65.5	25.8	393	.0					
Manganese steel (annealed), *C*, 1.298; *Mn*, 8.74; *S*, .024; *Si*, .094; *P*, .072. Hopkinson	63.2	24.9	380		1260			7.8	.282
Manganese steel (Hadfield), *C*, 1.005; *Mn*, 12.36; *S*, .038; *Si*, .204; *P*, .070. Hopkinson	65.5	25.8	393		1260			7.8	.282
Manganese steel (Hadfield), 12% *Mn*. Dewar and Fleming	67.1	26.4	401	.127	1260			7.8	.282
Manganese steel (Hadfield's Hecla Foundry), *C*, 1.001; *Mn*, 11.40; *P*, .059. Tests by G. E. Co	69.0	27.1	414	.135	1260			7.8	.282

Manganese steel. Hospitalier	75.0	29.5	450	.136	1260		230,000	7.8	.282
Copper, 70%; manganese, 30%. Feussner and Lindeck	101.0	39.8	605	.004					
Mercury. Matthiessen	94.3	37.1	566	.072		.032		13.6	.490
Nickel. Dewar and Fleming	12.3	4.85	73.7	.62	1500	.109		8.9	.321
Nickel (annealed). Matthiessen	12.4	4.89	74.4	.50	1500	.109		8.9	.321
Nickel steel (Hadfield), 4.35%; nickel. Dewar and Fleming	29.5	11.6	177	.201					
Nickeline. Lange & Co., Berlin	40.0	15.8	240						
Palladium (pure). Dewar and Fleming	10.2	4.02	61.1	.354					
Platinum, 67%; silver, 33% (alloy). Matthiessen	24.2	9.54	145	.133					
Platinum, 80%; iridium, 20%. Dewar and Fleming	30.9	12.2	186	.082					
Platinoid. Dewar and Fleming	41.7	16.4	251	.031				8.8	.318
Platinoid-martino. Dewar and Fleming	43.6	17.2	262					8.8	.318
Platinoid-martino	33.0	13.0	198	.024					
Platinum (soft annealed, pure)	8.25	3.24	49.5		1775	.032		21.2	.765
Platinum (annealed). Matthiessen	8.98	3.53	53.9	.247	1775	.032		21.2	.765

Platinum (pure) wire .0259 cm. in diam. Dewar and Fleming	11.0	4.34	66.0	.35	1775	.032		21.2	.765
Platinum, 90%; rhodium, 10%. Dewar and Fleming	21.1	8.30	127	.143					
Platinum, 90%; iridium, 10% (alloy). Matthiessen	21.6	8.50	130	.133					
Phosphor-bronze, with 9% phosphorus. Abbott	32.5	12.8	195						
Phosphor-bronze (copper, tin, and phosphorus). Hospitalier	1.6	.630	9.6	.394			64,000	8.9	.321
Phosphor-bronze (copper, tin, and phosphorus). Hospitalier	5.6	2.20	33.6	.394			117,000	8.9	.321
Phosphor-bronze, with 10% of tin. Abbott	24.6	9.69	148						
Pure electrolytic (annealed) silver. Dewar and Fleming	1.47	.579	8.82	.400	950	.056		10.5	.379
Silver (annealed). Matthiessen	1.49	.586	8.94	.377	950	.056		10.5	.379
Silverine, *Cu* (77), *Ni* (17), *Fe* (2), *Zn* (2), *CO* (2). Dewar and Fleming	2.06	.810	12.4	.285					
Silver, 80%; palladium 20% Dewar and Fleming	15.0	5.90	90.0						
Silver, 66%; platinum, 33% Dewar and Fleming	31.6	12.4	190	.0213					

Silicon-bronze (copper, tin, and silicon). Hospitalier	1.67	.657	10.0	.152			64,000	8.9	.321
Silicon-bronze (copper, tin, and silicon). Hospitalier	2.69	1.06	16.2				93,000	8.9	.321
Silicon-bronze (copper, tin, and silicon). Hospitalier	5.76	2.27	31.6				107,000	8.9	.321
Silicon-bronze (copper, tin, and silicon). Hospitalier	7.80	3.07	46.8				143,000	8.9	.321
Silicon steel (annealed), *C*, .685; *Mn*, .694; *S*, .024; *Si*, 3.44; *P*, .133. Hopkinson	61.9	24.3	372						
Thallium (pure). Dewar and Fleming	17.6	6.94	106	.398					
Tin (pure). Dewar and Fleming	13.1	5.16	78.5	.440	230	.056		7.3	.264
Tin (compressed). Matthiessen	13.1	5.16	78.5	.365	230	.056		7.3	.264
Tungsten steel (annealed), *C*, 1.36; *Mn*, .36; *S*, 0; *Si*, .043; *P*, .047; tungsten, 4.65. Hopkinson	22.5	8.86	135.0						
Whitworth soft steel (annealed), *C*, .090; *Mn*, .153; *S*, .016; *Si*, .0; *P*, .042. Hopkinson	10.8	4.25	64.8			.117		7.8	.282
Zinc (very pure). Dewar and Fleming	5.75	2.26	34.5	.406	415	.095		7.1	.256
Zinc (compressed) Matthiessen	5.80	2.28	34.8	.365	415	.095		7.1	.256

RESISTANCES AND TEMPERATURE COEFFICIENTS OF ELECTROLYTES

(Kohlrausch, Wiedemann's Annalen)

Composition	Per Cent.	5	10	15	20	25	30	35	40	50	60	70	80
Nitric Acid HNO_3	Ohms	3.90	2.18	1.64	1.41	1.31	*1.28*	1.31	1.37	1.59	1.96	2.54	3.76
	Temp.Coef.	1.50	1.40	1.40	1.40	1.40	1.40	1.40	1.50	1.6	1.6	1.5	1.3
Hydrochloric Acid HCl	Ohms	2.55	1.59	1.35	*1.32*	1.39	1.52	1.70	1.95				
	Temp.Coef.	1.60	1.60	1.60	1.50	1.50	1.50	1.50	1.50				
Sulphuric Acid H_2SO_4	Ohms	4.82	2.57	1.85	1.54	1.40	*1.36*	1.39	1.48	1.87	2.70	4.66	9.13
	Temp.Coef.	1.20	1.30	1.40	1.50	1.50	1.60	1.70	1.80	1.90	2.10	2.60	3.53
Silver Nitrate $AgNO_3$	Ohms	39.30	21.40	14.70	11.60	9.50	8.11	7.18	6.44	5.44	4.80		
	Temp.Coef.	2.20	2.20	2.20	2.10	2.10	2.10	2.10	2.10	2.10	2.10		
Caustic Potash KOH	Ohms	5.84	3.19	2.36	2.01	1.86	*1.85*	1.97	2.23				
	Temp.Coef.	1.90	1.90	1.90	2.00	2.10	2.30	2.40	2.70				
Zinc Sulphate $ZnSO_4$	Ohms	52.30	31.40	24.10	21.90	*21.40*	22.90	28.50					
	Temp.Coef.	2.20	2.30	2.30	2.40	2.60	3.00	4.00					

Copper Sulphate $CuSO_4$	Ohms	52.30	31.40	24.10									
	Temp.Coef.	2.20	2.30	2.30									
Magnesium Sulphate $MgSO_4$	Ohms	39.30	24.10	20.90	20.90	24.10							
	Temp.Coef.	2.30	2.40	2.50	2.70	2.90							
Sodium Sulphate Na_2SO_4	Ohms	24.80	14.70	11.30									
	Temp.Coef.	2.40	2.50	2.60									
Alum $KAl(SO_4)_2$	Ohms	39.30											
	Temp.Coef.	2.00											
Sodium Chloride $NaCl$	Ohms	14.90	8.33	6.15	5.14	4.70							
	Temp.Coef.	2.20	2.10	2.10	2.20	2.30							
Sal Ammoniac NH_4Cl	Ohms	10.90	5.67	3.89	2.98	2.50							
	Temp.Coef.	2.00	1.00	1.70	1.60	1.50							

of the table is that it presents in compact form recent information previously scattered through a large number of publications and technical journals.

In the last table the first horizontal line gives the per cent. by weight of the substance dissolved in water. The *specific resistance* of each substance (opposite the word "Ohms") is given in ohms at 18° C. between opposite parallel faces of a cube of the electrolyte 1 centimeter on a side. Opposite *temperature coefficient* is given the per cent. decrease of resistance per ohm for each degree increase of temperature. The resistance also varies with the density of the solution. The resistance of the best conducting sulphuric-acid solution is about 1,000,000 times that of copper.

Conductance (G).—Conductance is that property of a substance in virtue of which it conducts an electric current. The conductance of a piece of any material 1 cm. long and 1 sq. cm. in cross-section is called its *specific conductance*, or *conductivity*, and is represented by the Greek letter γ (gamma). The word *mho*, which is ohm spelled backwards, has been proposed as the name of the unit of conductance and conductivity, but it has not been generally accepted. Conductance is the reciprocal of resistance, and conductivity is the reciprocal of resistivity. Thus, if the resistance of 2 cm. of a piece of any material having a uniform sectional area of 1 sq. cm. is 4 ohms, its resistivity is 2 ohms, its conductance $\frac{1}{4}$ mho, and its conductivity $\frac{1}{2}$ mho. Percentage conductivity of a substance is the ratio of its conductivity to that of the standard at the same temperature. The conductivity of Matthiessen's pure copper at 0° C. is usually taken as the standard, i. e., 100%.

RESISTANCE OF CIRCUITS

Resistances in Series.—When a number of resistances are connected in series, the total resistance is equal to their sum.

Resistances in Parallel.—The joint resistance R of any number of resistances r_1, r_2, etc., in parallel, may be determined by the following formula, in the denominator of which

there should be as many terms as there are resistances in parallel:

$$R=\frac{1}{\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}+\frac{1}{r_4}+\text{ etc.}}$$

TEMPERATURE COEFFICIENT

The change in the resistance of a substance per ohm per degree change of temperature is known as the *temperature coefficient*. If R_0 is the resistance of a piece of wire at 0° C. and a is the temperature coefficient of the substance, its resistance R_t at t^0 may be calculated by the formula

$$R_t=R_0\,(1+at)$$

If the resistance R_0 is not known, but the resistance R_1 at a temperature t_1 is known, and it is desired to determine the resistance R_2 at a temperature t_2, the following formula may be used:

$$R_2=\frac{R_1(1+at_2)}{(1+at_1)}$$

The value of the temperature coefficient a taken from any table must be for Fahrenheit or centigrade scales, according to which is used in expressing t_1 and t_2. The American Institute of Electrical Engineers considers .0042 as the best value of a for commercial copper; for ordinary work it is quite customary to use the approximate value .004.

TEMPERATURE COEFFICIENTS FOR COPPER WIRE

The following table gives factors by which the known resistance of good commercial copper at any temperature from 31.5° F to 85° F., inclusive, may be multiplied to give its resistance at 75° F.; or, if the resistance at 75° F. is known, the resistance at any other temperature can be found by dividing the resistance at 75° by the factor corresponding to the other temperature. Also, if the resistance at any temperature is known, the resistance at any other temperature can be found by means of the factors; for example, multiplying a known resistance at 32° F. by the corresponding factor 1.1026 and dividing the product by the factor for 55° F. 1.0454, gives the resistance at 55° F.

TEMPERATURE FACTORS FOR COPPER WIRE

Temperature Degrees F.	Factor	Temperature Degrees F.	Factor	Temperature Degrees F.	Factor	Temperature Degrees F.	Factor
85.0	.9787	71.5	1.0077	58.0	1.0384	44.5	1.0708
84.5	.9797	71.0	1.0088	57.5	1.0395	44.0	1.0720
84.0	.9808	70.5	1.0099	57.0	1.0407	43.5	1.0733
83.5	.9818	70.0	1.0110	56.5	1.0419	43.0	1.0745
83.0	.9820	69.5	1.0121	56.0	1.0430	42.5	1.0757
82.5	.9839	69.0	1.0132	55.5	1.0442	42.0	1.0770
82.0	.9850	68.5	1.0144	55.0	1.0454	41.5	1.0783
81.5	.9861	68.0	1.0155	54.5	1.0466	41.0	1.0795
81.0	.9871	67.5	1.0166	54.0	1.0478	40.5	1.0808
80.5	.9882	67.0	1.0177	53.5	1.0490	40.0	1.0821
80.0	.9892	66.5	1.0188	53.0	1.0501	39.5	1.0833
79.5	.9903	66.0	1.0200	52.5	1.0513	39.0	1.0846
79.0	.9914	65.5	1.0211	52.0	1.0525	38.5	1.0858
78.5	.9924	65.0	1.0222	51.5	1.0537	38.0	1.0871
78.0	.9935	64.5	1.0233	51.0	1.0549	37.5	1.0884
77.5	.9046	64.0	1.0245	50.5	1.0561	37.0	1.0897
77.0	.9950	63.5	1.0257	50.0	1.0573	36.5	1.0910
76.5	.9967	63.0	1.0268	49.5	1.0585	36.0	1.0922
76.0	.9978	62.5	1.0279	49.0	1.0598	35.5	1.0935
75.5	.9989	62.0	1.0291	48.5	1.0610	35.0	1.0948
75.0	1.0000	61.5	1.0302	48.0	1.0622	34.5	1.0961
74.5	1.0011	61.0	1.0314	47.5	1.0634	34.0	1.0974
74.0	1.0022	60.5	1.0325	47.0	1.0646	33.5	1.0987
73.5	1.0033	60.0	1.0337	46.5	1.0659	33.0	1.1000
73.0	1.0044	59.5	1.0349	46.0	1.0671	32.5	1.1013
72.5	1.0055	59.0	1.0360	45.5	1.0683	32.0	1.1026
72.0	1.0066	58.5	1.0372	45.0	1.0695	31.5	1.1039

NOTE.—This table, which is given by Kempe in his "Handbook of Electrical Testing," is calculated from the exact formula $R_t = R_{32}\ [1 + .0023708\ (t - 32°) + .00000034548\ (t - 32°)^2]$, for pure, or good commercial, copper, as determined by Clark, Ford, and Taylor, in which t is expressed in degrees Fahrenheit.

Crocker's Method.—Dr. F. B. Crocker gives, for finding resistance of copper at any temperature $t°$ C the formula

$$R_t = R_0(1 + .004t + .0000024t^2)$$

This formula is easy to apply and gives very accurate results up to 100° C., being only .1% above those given by Matthiessen's formula for conductance G, which is as follows:

$$G_t = G_0(1 - .0038901t + .000009009t^2)$$

Kennelly's Method.—In applying the formula for resistance, it is usually necessary to work to or from R_0; to avoid this when changing from one temperature $t°$ to another $t° + u°$, Kennelly's method, which is as follows, may be used:

$$R_{t+u} = R_t(1 + au)$$

R_t is the resistance at $t°$ C., and a is the temperature coefficient at $t°$; the temperature coefficient varies with the initial temperature $t°$, and is given in the accompanying table. For example, if the resistance R_t, when $t = 25°$ C., is known, and the resistance at 30° is desired, then $u = 5°$ C., and

$t°C$	a
0	.0042
12	.0040
25	.0038
40	.0036

$$R_{30} = R_{25}\ (1 + .0038 \times 5) = 1.019\ R_{25}$$

In North America, the table and formulas given on page 88 are considered the best.

SIZES AND RESISTANCES OF WIRES

In expressing diameters of wires, .001 in. is called 1 *mil* and the square of the diameter of a wire in mils is called its area in *circular mils*. A wire 1 ft. long and 1 mil in diameter is 1 *mil-foot*. Resistance per mil-foot is a unit much used.

The resistance R of any conductor varies directly as the length of the conductor, and inversely as the sectional area. For a cylindrical wire

$$R = \frac{m \times l}{d^2}$$

in which m is the resistance per mil-foot, l is the length in feet, and d is the diameter in mils, d^2 being the sectional area in circular mils.

WIRE GAUGES

The Brown and Sharpe (B. & S.) gauge or American wire gauge (A. W. G.), as it is sometimes called, is generally used in the United States. Other gauges and their comparative diameters are also given in the following table, dimensions of wires being given in decimal parts of an inch.

VARIOUS WIRE GAUGES

Number of Wire Gauge	American, or Brown & Sharpe (B. & S.)	Birmingham, or Stubs (B. W. G.)	Washburn & Moen Mfg. Co., Worcester, Mass.	Trenton Iron Co., Trenton, N. J.	G. W. Prentiss, Holyoke, Mass.	Old English, From Brass Mfrs' List	British Standard (S. W. G.)	Number of Wire Gauge
0000000	.46000	.454	.460	.450	.3586	.08300	.500	0000000
000000	.40964	.425	.430	.400	.3282	.07200	.464	000000
00000	.36480	.380	.393	.360	.2994		.432	00000
0000	.32486	.340	.362	.330	.2777		.400	0000
000	.28930	.300	.331	.305	.2591		.372	000
00	.25763	.284	.307	.285	.2401		.348	00
0	.22942	.259	.283	.265	.2230		.324	0
1	.20431	.238	.263	.245	.2047		.300	1
2	.18194	.220	.244	.225	.1885		.276	2
3	.16202	.203	.225	.205	.1758		.252	3
4	.14428	.180	.207	.190	.1605		.232	4
5	.12849	.165	.192	.175	.1471		.212	5
6	.11443	.148	.177	.160	.1351		.192	6
7	.10189	.134	.162	.145	.1205		.176	7
8	.090742	.120	.148	.130	.1065		.160	8
9	.080808	.109	.135	.1175	.0928		.144	9
10	.071961	.095	.120	.1050	.0816		.128	10
11	.064084	.083	.105	.0925	.0726		.116	11
12	.057068	.072	.0920	.0800			.104	12
13			.0800	.0700			.0920	13
14			.0720				.0800	14
15							.0720	15

16	.050820	.065	.0630	.0610	.0627	.06500	.0640	16
17	.045257	.058	.0540	.0525	.0546	.05800	.0560	17
18	.040303	.049	.0470	.0450	.0478	.04900	.0480	18
19	.035890	.042	.0410	.0400	.0411	.04000	.0400	19
20	.031961	.035	.0350	.0350	.0351	.03500	.0360	20
21	.028462	.032	.0320	.0310	.0321	.03150	.0320	21
22	.025347	.028	.0280	.0280	.0290	.02950	.0280	22
23	.022571	.025	.0250	.0250	.0261	.02700	.0240	23
24	.020100	.022	.0230	.0225	.0231	.02500	.0220	24
25	.017900	.020	.0200	.0200	.0212	.02300	.0200	25
26	.015940	.018	.0180	.0180	.0194	.02050	.0180	26
27	.014195	.016	.0170	.0170	.0182	.01875	.0164	27
28	.012641	.014	.0160	.0160	.0170	.01650	.0148	28
29	.011257	.013	.0150	.0150	.0163	.01550	.0136	29
30	.010025	.012	.0140	.0140	.0156	.01375	.0124	30
31	.008928	.010	.0130	.0130	.0146	.01225	.0116	31
32	.007950	.009	.0120	.0120	.0136	.01125	.0108	32
33	.007080	.008	.0110	.0110	.0130	.01025	.0100	33
34	.006305	.007	.0100	.0100	.0118	.00950	.0092	34
35	.005615	.005	.0095	.0095	.0109	.00900	.0084	35
36	.005000	.004	.0090	.0090	.0100	.00750	.0076	36
37	.004453		.0085	.0085	.0095	.00650	.0068	37
38	.003965		.0080	.0080	.0090	.00575	.0066	38
39	.003531		.0075	.0075	.0083	.00500	.0052	39
40	.003145		.0070	.0070	.0078	.00450	.0048	40
41							.0044	41
42							.0040	42

TEMPERATURE COEFFICIENTS FOR COPPER

(i is the initial temperature in degrees C; a, the temperature coefficient in per cent. per ohm per degree C.)

i	*a*	*i*	*a*	*i*	*a*
0	.4200	17	.3920	34	.3675
1	.4182	18	.3905	35	.3662
2	.4165	19	.3890	36	.3648
3	.4148	20	.3875	37	.3635
4	.4131	21	.3860	38	.3622
5	.4114	22	.3845	39	.3609
6	.4097	23	.3830	40	.3596
7	.4080	24	.3815	41	.3583
8	.4063	25	.3805	42	.3570
9	.4047	26	.3786	43	.3557
10	.4031	27	.3772	44	.3545
11	.4015	28	.3758	45	.3532
12	.3999	29	.3744	46	.3520
13	.3983	30	.3730	47	.3508
14	.3967	31	.3716	48	.3495
15	.3951	32	.3702	49	.3483
16	.3936	33	.3689	50	.3471

The American Institute of Electrical Engineers gives this table and following formulas for calculating resistance of copper wire at a temperature $u°$ C. above an initial temperature $i°$ C. and the rise in degrees C. above an initial temperature $i°$ C.:

$$R_{i+u}=R_i\left(1+\frac{au}{100}\right)$$

$$u=(238.1+i)\left(\frac{R_{i+u}}{R_i}-1\right)$$

in which a is the temperature coefficient given in the table corresponding to the initial temperature $i°$ C., and u is the rise in temperature above the initial temperature $i°$ C.

COPPER WIRE

The specific gravity of pure annealed copper at 60° F. is 8.89 to 8.91. One cubic inch of it weighs .32 lb., and its melting point is about 2,100° F. By the process of hard drawing, the tensile strength of copper is greatly increased

without greatly decreasing its conductivity. Since the conductivity varies, even with a variation of less than .02 of 1% of impurity, scarcely two samples can be obtained with exactly the same conductivity. Authorities very seldom agree on the specific resistance or temperature coefficient of copper.

Matthiessen's Standards.—Copper-wire tables are usually based on the grade of copper used by Matthiessen in determining the resistance of copper. The following are based on his measurements on copper with a specific gravity of 8.89.

Dimensions	Resistance at 0° C. International Ohms
Mil-foot soft copper	9.590
Meter-gram soft copper	.141729
Meter-millimeter soft copper	.02030
Centimeter cube soft copper	.000001594
Meter-gram hard-drawn copper	.1449
Ratio hard- to soft-drawn copper	1.0226

COPPER-WIRE TABLES

In the copper-wire tables to follow, the values in the columns marked † at the top are taken from the table prepared by the American Institute of Electrical Engineers and are correct to one part in two thousand. These values were computed for Matthiessen's standard copper from the data in the preceding table, and from temperature coefficients of resistance for 20° C. = 1.07968, for 50° C. = 1.20625, and for 80° C = 1.33681; 1 ft. = .3048028 m.; 1 lb. = 453.59256 g.

Matthiessen's standard of resistivity may be permanently recognized, but the temperature coefficient that he introduced, and which is here used, may in future undergo slight revision. The values in the columns marked with a * were computed especially for this pocketbook from data given in other parts of the table and the ratio of resistivity of hard to soft copper.

The average of a number of the most reliable determinations gives the resistance of a meter-gram of pure annealed

SIZE AND WEIGHT OF ANNEALED COPPER WIRE

(B. & S. Gauge, Specific Gravity, 8.89)

B. & S. Gauge	Diameter in Mils d †	Area in Circular Mils d^2 †	Area in Sq. In. $\frac{d^2 \times .7854}{1{,}000{,}000}$ *	Pounds per 1,000 Feet †	Pounds per Mile *	Feet per Pound †
0000	460.00	211,600	.16619	640.5	3.381.4	1.561
000	409.64	167,805	.13179	508.0	2 682.2	1.969
00	364.80	133,079	.10452	402.8	2.126.8	2.482
0	324.86	105,534	.082887	319.5	1,686.9	3.130
1	289.30	83,694	.065732	253.3	1,337.2	3.947
2	257.63	66,373	.052128	200.9	1,060.6	4.977
3	229.42	52,634	.041339	159.3	841.09	6.276
4	204.31	41,742	.032784	126.4	667.39	7.914
5	181.94	33,102	.025999	100.2	529.06	9.980
6	162.02	26,250	.020618	79.46	419.55	12.58
7	144.28	20,816	.016351	63.02	332.75	15.87
8	128.49	16,509	.012967	49.98	263.89	20.01
9	114.43	13 094	.010283	39.63	209.24	25.23
10	101.89	10,381	.0081548	31.43	165.95	31.82
11	90.742	8.234.0	.0064656	24.93	131.63	40.12
12	80.808	6,529.9	.0051287	19.77	104.39	50.59
13	71.961	5,178.4	.0040672	15.68	82.791	63.79
14	64.084	4,106.8	.0032254	12.43	76.191	80.44
15	57.068	3,256.7	.0025579	9.858	52.050	101.4

16	50.820	2,582.9	.0020285	7.818	41.277	127.9
17	45.257	2,048.2	.0016087	6.200	32.736	161.3
18	40.303	1,624.3	.0012757	4.917	25.960	203.4
19	35.890	1,288.1	.0010117	3.899	20.595	256.5
20	31.961	1,021.5	.00080231	3.092	16.324	323.4
21	28.462	810.10	.00063626	2.452	12.946	407.8
22	25.347	642.40	.00050457	1.945	10.268	514.2
23	22.571	509.45	.00040015	1.542	8.142	684.4
24	20.100	404.01	.00031733	1.223	6.457	817.6
25	17.900	320.40	.00025166	.9699	5.121	1020
26	15.940	254.10	.00019958	.7692	4.061	1300
27	14.195	201.50	.00015827	.6100	3.221	1639
28	12.641	159.79	.00012551	.4837	2.554	2067
29	11.257	126.72	.00009536	.3836	2.025	2607
30	10.025	100.50	.00007893	.3042	1.606	3287
31	8.928	79.70	.00006259	.2413	1.274	4145
32	7.950	63.21	.00004964	.1913	1.010	5227
33	7.080	50.13	.00003936	.1517	.801	6591
34	6.305	39.75	.00003122	.1203	.635	8311
35	5.615	31.52	.00002475	.09543	.504	10480
36	5.000	25.00	.00001963	.07568	.400	13210
37	4.453	19.82	.00001557	.06001	.317	16660
38	3.965	15.72	.00001234	.04759	.251	21010
39	3.531	12.47	.00000979	.03774	.199	26500
40	3.145	9.89	.00000776	.02993	.158	33410

RESISTANCE OF ANNEALED COPPER WIRE

(B. & S. Gauge)

B. & S. Gauge	Pounds per Ohm			Feet per Ohm		
	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F †
0000	13,090	11,720	10,570	20,440	18,290	16,510
000	8,232	7,369	6,647	16,210	14,510	13,090
00	5,177	4,634	4,182	12,850	11,500	10,380
0	3,256	2,914	2,630	10,190	9,123	8,232
1	2,048	1,833	1,654	8,083	7,235	6,528
2	1,288	1,153	1,040	6,410	5,738	5,177
3	810.0	725.0	654.2	5,084	4,550	4,106
4	509.4	455.9	411.4	4,031	3,608	3,256
5	320.4	286.7	258.7	3,197	2,862	2,582
6	201.5	180.3	162.7	2,535	2,269	2,048
7	126.7	113.4	102.3	2,011	1,800	1,624
8	79.69	71.33	64.36	1,595	1,427	1,288
9	50.12	44.86	40.48	1,265	1,132	1,021
10	31.52	28.21	25.46	1,003	897.6	809.9
11	19.82	17.74	16.01	795.3	711.8	642.3
12	12.47	11.16	10.07	630.7	564.5	509.4
13	7.840	7.017	6.332	500.1	447.7	404.0
14	4.931	4.413	3.982	396.6	355.0	320.3

15	3.101	2.776	2.504	314.5	281.5	254.0
16	1.950	1.746	1.575	249.4	223.3	201.5
17	1.226	1.098	.9906	197.8	177.1	159.8
18	.7713	.6904	.6230	156.9	140.4	126.7
19	.4851	.4342	.3918	124.4	111.4	100.5
20	.3051	.2731	.2464	98.66	88.31	79.68
21	.1919	.1717	.1550	78.24	70.03	63.19
22	.1207	.1080	.09746	62.05	55.54	50.11
23	.07589	.06793	.06129	49.21	44.04	39.74
24	.04773	.04272	.03855	39.02	34.93	31.52
25	.03002	.02687	.02424	31.29	28.01	24.99
26	.01888	.01690	.01525	24.54	21.97	19.82
27	.01187	.01063	.009588	19.46	17.42	15.72
28	.007466	.006683	.006030	15.43	13.82	12.47
29	.004696	.004203	.003792	12.24	10.96	9.886
30	.002953	.002643	.002385	9.707	8.688	7.840
31	.001857	.001662	.001500	7.698	6.890	6.217
32	.001168	.001045	.0009436	6.105	5.464	4.930
33	.0007346	.0006575	.0005933	4.841	4.333	3.910
34	.0004620	.0004135	.0003731	3.839	3.436	3.101
35	.0002905	.0002601	.0002347	3.045	2.725	2.459
36	.0001827	.0001636	.0001476	2.414	2.161	1.950
37	.0001149	.0001029	.00009281	1.915	1.714	1.547
38	.00007210	.00006454	.00005824	1.519	1.359	1.226
39	.00004545	.00004068	.00003671	1.204	1.078	.9726
40	.00002858	.00002559	.00002309	.9550	.8548	.7713

RESISTANCE OF ANNEALED COPPER WIRE

(B. & S. Gauge)

B. & S. Gauge	Ohms per Pound			Ohms per 1,000 Feet		
	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †
0000	.00007639	.00008535	.00009459	.04893	.05467	.06058
000	.0001215	.0001357	.0001504	.06170	.06404	.07640
00	.0001931	.0002158	.0002391	.07780	.08692	.09633
0	.0003071	.0003431	.0003803	.09811	.1096	.1215
1	.0004883	.0005456	.0006046	.1237	.1382	.1532
2	.0007765	.0008675	.0009614	.1560	.1743	.1932
3	.001235	.001379	.001529	.1967	.2198	.2435
4	.001963	.002193	.002431	.2480	.2771	.3071
5	.003122	.003487	.003865	.3128	.3495	.3873
6	.004963	.005545	.006145	.3944	.4406	.4883
7	.007892	.008817	.009772	.4973	.5556	.6158
8	.01255	.01402	.01554	.6271	.7007	.7765
9	.01995	.02229	.02471	.7908	.8835	.9791
10	.03173	.03545	.03928	.9972	1.114	1.235
11	.05045	.05636	.06246	1.257	1.405	1.557
12	.08022	.08962	.09932	1.586	1.771	1.963
13	.1276	.1425	.1579	1.999	2.234	2.476
14	.2028	.2266	.2511	2.521	2.817	3.122

15	.3225	.3603	.3993	3.179	3.552	3.936
16	.5128	.5729	.6349	4.009	4.479	4.964
17	.8153	.9109	1.010	5.055	5.648	6.259
18	1.296	1.448	1.605	6.374	7.122	7.892
19	2.061	2.303	2.552	8.038	8.980	9.952
20	3.278	3.662	4.058	10.14	11.32	12.55
21	5.212	5.823	6.453	12.78	14.28	15.83
22	8.287	9.259	10.26	16.12	18.01	19.96
23	13.18	14.72	16.32	20.32	22.71	25.16
24	20.95	23.41	25.94	25.63	28.63	31.73
25	33.32	37.22	41.25	32.31	36.10	40.01
26	52.97	59.18	65.59	40.75	45.52	50.45
27	84.23	94.11	104.3	51.38	57.40	63.62
28	133.9	149.6	165.8	64.79	72.39	80.22
29	213.0	237.9	263.7	81.70	91.28	101.2
30	338.6	378.3	419.3	103.0	115.1	127.6
31	538.4	601.6	666.7	129.9	145.1	160.8
32	856.2	956.5	1060	163.8	183.0	202.8
33	1361	1521	1685	206.6	230.8	255.8
34	2165	2418	2680	260.5	291.0	322.5
35	3441	3845	4262	328.4	366.9	406.7
36	5473	6114	6776	414.2	462.7	512.9
37	8702	9722	10770	522.2	583.5	646.6
38	13870	15490	17170	658.5	735.7	815.4
39	22000	24580	27240	830.4	927.7	1,028
40	34980	39080	43320	1,047	1,170	1,296

RESISTANCE OF ANNEALED AND HARD-DRAWN COPPER WIRE

(B. & S. Gauge)

B. & S. Gauge	Annealed Ohms per Mile	Hard-Drawn. At 20° C. or 68° F.		
	At 20° C. or 68° F.	Ohms per Pound *	Ohms per 1,000 Feet *	Ohms per Mile *
0000	.25835	.00007812	.050036	.26419
000	.32577	.0001242	.063094	.33314
00	.41079	.0001975	.079558	.42007
0	.51802	.0003140	.10033	.52973
1	.65314	.0004993	.12649	.66790
2	.82368	.0007940	.15953	.84230
3	1.0386	.001263	.20114	1.0621
4	1.3094	.002007	.25361	1.3392
5	1.6516	.003193	.31987	1.6889
6	2.0825	.005075	.40332	2.1295
7	2.6258	.008070	.50854	2.6850
8	3.3111	.01283	.64127	3.3859
9	4.1753	.02040	.80876	4.2769
10	5.2657	.03245	1.0199	5.3848
11	6.6369	.05159	1.2854	6.7869
12	8.3741	.08203	1.6218	8.5633

13	10.555	.1305	2.0443	10.794
14	13.311	.2074	2.5779	13.612
15	16.785	.3298	3.2508	17.165
16	21.168	.5244	4.0996	21.646
17	26.691	.8337	5.1692	27.294
18	33.655	1.325	6.5183	34.416
19	42.441	2.108	8.2196	43.400
20	53.539	3.352	10.372	54.749
21	67.479	5.330	13.069	78.004
22	85.114	8.444	16.484	87.038
23	107.29			
24	135.53			
25	170.59			
26	215.16			
27	271.29			
28	342.09			
29	431.37			
30	543.84			
31	685.87			
32	864.87			
33	1,090.8			
34	1,375.5			
35	1,734.9			
36	2,187.0			
37	2,757.3			
38	3,476.8			
39	4,384.5			
40	5,528.2			

NOTE.—In these tables, the resistances are all based on Matthiessen's Standard.

SIZE AND WEIGHT OF ANNEALED COPPER WIRE

(B. W. G. or Stubbs Gauge; Specific Gravity, 8.89)

Gauge No. (B. W. G.)	Diameter in Mils d	Area in Circular Mils d^2 †	Pounds per 1,000 Feet †	Pounds per Mile *	Pounds per Ohm		
					At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †
0000	454	206,116	623.9	3,294	12,420	11,120	10,570
000	425	180,625	546.8	2,887	9,538	8,537	7,702
00	380	144,400	437.1	2,308	6,096	5,456	4,924
0	340	115,600	349.9	1,847	3,907	3,497	3,155
1	300	90,000	272.4	1,438	2,368	2,120	1,913
2	284	80,656	244.1	1,289	1,902	1,702	1,536
3	259	67,081	203.1	1,072	1,316	1,178	1,063
4	238	56,644	171.5	905	938.0	839.6	757.6
5	220	48,400	146.5	773	684.9	613.0	553.1
6	203	41,209	124.7	659	496.5	444.4	401.0
7	180	32,400	98.08	518	306.9	274.7	247.9
8	165	27,225	82.41	435	216.7	194.0	175.0
9	148	21,904	66.30	350	140.3	125.6	113.3
10	134	17,956	54.35	287	94.26	84.37	76.13
11	120	14,400	43.59	230	60.62	54.26	48.96
12	109	11,881	35.96	190	41.27	36.94	33.33
13	95	9,025	27.32	144	23.81	21.31	19.23

14	83	6,889	20.85	110	13.87	12.42	11.21
15	72	5,184	15.69	83.0	7.857	7.032	6.346
16	65	4,225	12.79	68.0	5.219	4.671	4.215
17	58	3,364	10.18	54.0	3.308	2.961	2.672
18	49	2,401	7.268	38.4	1.658	1.509	1.361
19	42	1,764	5.340	28.2	.9097	.8143	.7347
20	35	1,225	3.708	19.6	.4387	.3927	.3543
21	32	1,024	3.100	16.4	.3066	.2744	.2476
22	28	784	2.373	12.5	.1797	.1608	.1451
23	25	625	1.892	10.0	.1142	.1022	.09224
24	22	484	1.465	7.70	.06849	.06130	.05531
25	20	400	1.211	6.40	.04678	.04187	.03778
26	18	324	9.808	5.20	.03069	.02747	.02479
27	16	256	.7749	4.10	.01916	.01715	.01548
28	14	196	.5933	3.10	.01123	.01005	.009071
29	13	169	.5116	2.70	.008350	.007474	.006744
30	12	144	.4359	2.30	.006062	.005426	.004896
31	10	100	.3027	1.60	.002924	.002617	.002361
32	9	81	.2452	1.30	.001918	.001717	.001549
33	8	64	.1937	1.02	.001197	.001072	.0009672
34	7	49	.1483	.780	.0007019	.0006283	.0005669
35	5	25	.07568	.400	.0001827	.0001636	.0001476
36	4	16	.04843	.256	.00007484	.00006699	.00006045

LENGTH AND RESISTANCE OF ANNEALED COPPER WIRE

(B. W. G. or Stubbs Gauge)

Gauge No. (B.W.G.)	Feet per Pound †	Feet per Ohm			Ohms per Pound		
		At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †
0000	1.603	19,910	17,820	16,080	.00008051	.00008996	.00009969
000	1.829	17,450	15,620	14,090	.0001048	.0001171	.0001298
00	2.288	13,950	12,480	11,260	.0001640	.0001833	.0002031
0	2.858	11,160	9,993	9,017	.0002560	.0002860	.0003169
1	3.671	8,692	7,780	7,020	.0004223	.0004718	.0005228
2	4.096	7,790	6,973	6,292	.0005258	.0005874	.0006510
3	4.925	6,479	5,799	5,233	.0007601	.0008492	.0009412
4	5.832	5,471	4,897	4,419	.001066	.001191	.001320
5	6.826	4,675	4,184	3,775	.001460	.001631	.001808
6	8.017	3,980	3,562	3,215	.002014	.002250	.002494
7	10.20	3,129	2,801	2,527	.003258	.003640	.004034
8	12.13	2,629	2,354	2,124	.004615	.005156	.005714
9	15.08	2,116	1,894	1,709	.007129	.007965	.008827
10	18.40	1,734	1,552	1,401	.01061	.01185	.01314
11	22.94	1,391	1,245	1,123	.01650	.01843	.02042
12	27.81	1,147	1,027	926.9	.02423	.02707	.03000
13	36.60	871.7	780.2	704.0	.04199	.04692	.05200
14	47.95	665.4	595.5	537.4	.07207	.08052	.08924

15	63.73	500.7	448.1	404.4	.1273	.1422	.1576
16	78.19	408.1	365.2	329.6	.1916	.2141	.2373
17	98.23	324.9	290.8	262.4	.3023	.3377	.3742
18	137.6	231.9	207.6	187.3	.5933	.6629	.7346
19	187.3	170.4	152.5	137.6	1.099	1.228	1.361
20	269.7	118.3	105.9	95.56	2.279	2.547	2.822
21	322.6	98.10	88.52	79.88	3.262	3.644	4.039
22	421.4	75.72	67.78	61.16	5.565	6.217	6.890
23	528.6	60.36	54.03	48.75	8.756	9.783	10.84
24	682.6	46.75	41.84	37.75	14.60	16.31	18.08
25	825.9	38.63	34.58	31.20	21.38	23.88	26.47
26	1,020	31.29	28.01	25.27	32.58	36.40	40.34
27	1,290	24.73	22.13	19.97	52.19	58.31	64.62
28	1,685	18.93	16.94	15.29	89.04	99.48	110.2
29	1,955	16.32	14.61	13.18	119.8	133.8	148.3
30	2,294	13.91	12.45	11.23	165.0	184.3	204.2
31	3,304	9.658	8.645	7.800	342.0	382.1	423.5
32	4,078	7.823	7.002	6.318	521.3	582.5	645.5
33	5,162	6.181	5.533	4.992	835.1	933.0	1,034
34	6,742	4.733	4.236	3.822	1,425	1,792	1,764
35	13,210	2.414	2.161	1.950	5,473	6,114	6,776
36	20,650	1.545	1.383	1.248	13,360	14,930	16,540

RESISTANCE OF ANNEALED AND HARD-DRAWN COPPER WIRE

(B. W. G. or Stubbs Gauge)

Gauge No. (B. W. G.)	Annealed				Hard-Drawn. At 20° C. or 68° F.		
	Ohms per 1,000 Ft.			Ohms per Mile At 20° C. or 68° F. *	Ohms per Pound *	Ohms per 1,000 Feet *	Ohms per Mile *
	At 20° C. or 68° F. †	At 50° C. or 122° F. †	At 80° C. or 176° F. †				
0000	.05023	.05612	.06220	.2652	.00008233	.05137	.2712
000	.05732	.06404	.07097	.3026	.0001072	.05862	.3095
00	07170	.08011	.08878	.3786	.0001677	.07332	.3871
0	.08957	.1001	.1109	.4729	.0002618	.09159	.4836
1	.1150	.1285	.1424	.6072	.0004318	.1176	.6209
2	.1284	.1434	.1589	.6780	.0005377	.1313	.6833
3	.1543	.1724	.1911	.8147	.0007773	.1578	.8332
4	.1828	.2042	.2263	.9652	.001090	.1869	.9868
5	.2139	.2390	.2649	1.129	.001493	.2187	1.155
6	.2513	.2807	.3111	1.327	.002060	.2570	1.357
7	.3196	.3570	.3957	1.687	.003331	.3268	1.726
8	.3803	.4249	.4709	2.008	.004719	.3889	2.053
9	.4727	.5281	.5853	2.496	.007290	.4834	2.552
10	.5766	.6442	.7140	3.044	.01085	.5896	3.113

11	.7190	.8033	.8903	3.796	.01687	.7352	**3.882**
12	.8715	.9736	1.079	4.602	.02479	.8912	4.706
13	1.147	1.282	1.420	6.056	.04294	1.173	6.193
14	1.503	1.679	1.861	7.936	.07370	1.537	8.115
15	1.997	2.231	2.473	10.54	.1302	2.042	10.78
16	2.451	2.738	3.034	12.94	.1959	2.506	13.23
17	3.078	3.439	3.811	16.52	.3101	3.148	16.62
18	4.312	4.818	5.339	22.77	.6067	4.409	23.28
19	5.870	6.558	7.267	30.99	1.124	6.003	31.70
20	8.452	9.443	10.47	44.63	2.331	8.643	45.64
21	10.11	11.30	12.52	53.38	3.336	10.34	54.60
22	13.21	14.75	16.35	69.75	5.691	13.51	71.33
23	16.57	18.51	20.51	87.49	8.954	16.94	89.44
24	21.39	23.90	26.49	112.9	14.93	21.87	115.5
25	25.88	28.92	32.05	136.6	21.86		
26	31.96	35.70	39.57	168.7	33.32		
27	40.45	45.19	50.08	213.6	53.37		
28	52.83	59.02	65.41	278.9	91.05		
29	61.27	68.45	75.86	323.5	122.5		
30	71.90	80.33	89.03	379.6	168.7		
31	103.5	115.7	128.2	546.5	349.7		
32	127.8	144.8	158.3	674.8	533.1		
33	161.8	180.7	200.3	854.3	854.0		
34	211.3	236.1	261.6	1,116	1,457		
35	414.2	462.7	512.9	2,187	5,597		
36	647.1	723.0	801.1	3,417	13,660		

APPROXIMATE WEIGHTS OF WEATHER-PROOF WIRE

(*American Electrical Works*)

TRIPLE-BRAIDED INSULATION

Size	Feet per Pound	Pounds per 1,000 Ft.	Pounds per Mile	Ampere Capacity Allowed by Fire Underwriters
0000	1.34	742	3,920	312
000	1.64	609	3,215	262
00	2.05	487	2,570	220
0	2.59	386	2,040	185
1	3.25	308	1,625	156
2	4.10	244	1,289	131
3	5.15	194	1,025	110
4	6.26	160	845	92
5	7.46	134	710	77
6	9.00	111	585	65
8	13.00	73	385	46
10	20.00	50	265	32
12	29.00	35	182	23
14	38.00	26	137	16
16	48.00	21	113	8
18	67.00	15	81	5

DOUBLE-BRAIDED INSULATION

0000	1.40	711	3,754	312
000	1.75	570	3,010	262
00	2.29	436	2,300	220
0	2.81	355	1,875	185
1	3.56	281	1,482	156
2	4.49	223	1,175	131
3	5.45	184	969	110
4	6.82	147	774	92
5	9.10	110	580	77
6	10.35	97	510	65
8	15.52	64	340	46
10	22.00	45	237	32
12	40.00	25	132	23
14	56.00	18	95	16
16	76.00	13	69	8
18	100.00	10	53	5

ommercial copper as .1486 ohm at 60° F. In England, atthiessen's values, .150822 ohm for a meter-gram of nnealed high-conductivity commercial copper and .153858 m for a meter-gram of hard-drawn high-conductivity commercial copper, both at 60° F. and having a temperature efficient of .00238 per degree F., are considered as standards.

STANDARD WEATHER-PROOF FEED-WIRE

(*Roebling's*)

Circular Mils	Outside Diameters Inches	Weights Pounds		Approximate Length on Reels Feet	Carrying Capacity, National Board Fire Underwriters
		1,000 Ft.	Mile		
,000,000	$1\frac{1}{2}$	3,550	18,744	800	1,000
900,000	$1\frac{13}{32}$	3,215	16,975	800	920
800,000	$1\frac{11}{32}$	2,880	15,206	850	840
750,000	$1\frac{5}{16}$	2,713	14,325	850	
700,000	$1\frac{9}{32}$	2,545	13,438	900	760
650,000	$1\frac{1}{4}$	2,378	12,556	900	
600,000	$1\frac{7}{32}$	2,210	11,668	1,000	680
550,000	$1\frac{3}{16}$	2,043	10,787	1,200	
500,000	$1\frac{1}{8}$	1,875	9,900	1,320	590
450,000	$1\frac{3}{32}$	1,703	8,992	1,400	
400,000	$1\frac{1}{16}$	1,530	8,078	1,450	500
350,000	1	1,358	7,170	1,500	
300,000	$\frac{15}{16}$	1,185	6,257	1,600	400
250,000	$\frac{29}{32}$	1,012	5,343	1,600	

Carl Herring advocates the following values: resistance 1 mil-foot at 15° C., 10.0275 international ohms, as given Prof. Lindeck for pure copper, and 10.1478 international ms for Matthiessen's standard copper; resistivity (per ntimeter cube) at 15° C., 1.667 microhms, as given by of. Lindeck for pure copper, and 1.687 microhms for atthiessen's standard copper.

Joints in aluminum and hard-drawn copper telephone and telegraph line wires should always be made with McIntire or similar sleeves made of the same metal as the wire. When making a McIntire sleeve joint, pass each end of the wire through the sleeve until it extends ¼ inch beyond the end of the sleeve, then place a steel tie-wrench or connector on each end of the sleeve, the outside of the tool to be ¼ inch from

HARD-DRAWN COPPER WIRE

Diameter in Mils	Gauge and Number	Weight per Mile in Pounds	Resistance per Mile in Ohms at 60° F.
165	8 B. W. G.	435	1.9742
162	6 B. & S. G.	419	2.0481
160	8 N. B. S. G.	409	2.0998
148	9 B. W. G.	350	2.4541
144.3	7 B. & S. G.	331	2.5925
144	9 N. B. S. G.	331	2.5925
134	10 B. W. G.	287	2.9835
128.5	8 B. & S. G.	262	3.2810
128	10 N. B. S. G.	262	3.2810
120	11 B. W. G.	230	3.7330
116	11 N. B. S. G.	215	3.9948
114.4	9 B. & S. G.	208	4.1363
109	12 B. W. G.	190	4.5244
104	12 N. B. S. G.	173	4.9701
101.9	10 B. & S. G.	166	5.1665
95	13 B. W. G.	144	5.9558
92	13 N. B. S. G.	135	6.3518
90.74	11 B. & S. G.	132	6.4891
83	14 B. W. G.	110	7.8038
80.81	12 B. & S. G.	105	8.1946
80	14 N. B. S. G.	102	8.4005

N. B. S. stands for the New British Standard wire gauge.

the end of the sleeve, after which 3 to 4½ complete turns, depending on the size of the wire, should be made, using great care to keep the sleeve absolutely straight. For No. 8 B. W. G. wire give 4½ turns, for sizes more extensively used give 3 turns and use sleeves of proper size to fit the wire. Full-length and half-length sleeves are made, the former for through line joints and the latter for branch joints.

HARD-DRAWN COPPER WIRE

Number and Gauge	Diameters in Mils			Weights per Mile			Breaking Weights		Weights of Coils		Conductivity		Twist in 6 In.	Per Cent. Elongation in 5 Ft.
	Required	Maximum	Minimum	Required	Maximum	Minimum	Actual Required	Per Square Inch	Maximum	Minimum	Required	Minimum		
8 B.W.G.	165.0	166.0	164.0	436.4	441.7	431.1	1,328	62,108	218	152	97	96	30	1.14
12 N.B.S. *	104.0	104.7	103.3	173.4	175.7	171.1	549	64,600	219	151	97	96	40	1.00
10 B. & S.	101.9	102.8	101.0	165.0	168.0	162.0	540	64,800	218	152	97	96	40	.99
12 B. & S.	80.8	81.3	80.3	104.7	106.0	103.4	336	65,500	72	52	97	96	44	.95
14 B. & S.	64.0	65.0	63.0	65.0	67.5	63.0	220	68,200			97	96	47	.91
16 B.W.G.	65.0	65.5	64.5		68.8	66.7	220	66,200				96		.91
14 N.B.S.	80.0	80.5	79.5		103.9	101.3	330	65,600				96		.94
13 N.B.S.	92.0	92.6	91.4		137.5	133.9	433	65,100				96		.97
10 N.B.S.	128.0	128.8	127.2		265.9	259.4	820	63,700				96		1.06
10 B.W.G.	134.0	134.9	133.1		291.7	284.0	894	63,400				96		1.07

*N. B. S. stands for the New British Standard wire gauge for which S. W. G. is sometimes used.

TENSILE STRENGTH OF COPPER WIRE

Nos. B. & S. Gauge	Breaking Weight in Pounds		Nos. B. & S. Gauge	Breaking Weight in Pounds	
	Hard-Drawn	Annealed		Hard-Drawn	Annealed
0000	8,310	5,650	9	617	349
000	6,580	4,480	10	489	277
00	5,226	3,553	11	388	219
0	4,558	2,818	12	307	174
1	3,746	2,234	13	244	138
2	3,127	1,772	14	193	109
3	2,480	1,405	15	153	87
4	1,967	1,114	16	133	69
5	1,559	883	17	97	55
6	1,237	700	18	77	43
7	980	555	19	61	34
8	778	440	20	48	27

DATA ON DOUBLE SILK-COVERED COPPER WIRE

B. & S. Gauge No.	o = Ohms per Cubic Inch	u	Pounds per Cubic Inch
20	.76	.79	.24
22	2.0	.69	.23
24	5.0	.62	.21
26	12.0	.55	.19
28	25.0	.49	.17
30	54.0	.43	.14
32	105.0	.37	.12
34	195.0	.31	.08
36	355.0	.25	.075
38	630.0	.19	.06
40	1,050.0	.13	.05

NOTE.—u is the portion of the total volume that is occupi by the copper alone, the difference $1-u$ being the porti occupied by the insulation.

IRON WIRE

There are three grades of iron wire; namely, Extra Best Best (E. B. B.), which has the highest conductivity and is the most uniform in quantity, being both tough and pliable; Best Best (B. B.), which is less uniform and tough, lower in conductivity, frequently sold as E. B. B.; and Best, which is the poorest grade made, being still less uniform, more brittle, and lowest in conductivity.

MECHANICAL AND ELECTRICAL TESTS OF IRON WIRE OF AMERICAN MANUFACTURE

The column headed "Percentage Conductivity" in the following table gives the percentages that the conductivities of the various samples bear to the conductivity of pure copper. "Percentage of Elongation" means the percentage of the length the wire elongated before breaking. The column headed "Relative Breaking Stress" gives the number of feet of its own length that each sample was able to sustain.

Specifications.—Iron wire for use on telegraph and telephone lines should conform to the following specifications of the Western Union Telegraph Company:

1. The wire must be soft and pliable, and be capable of elongating 15%, without breaking, after being galvanized.

2. Great tensile strength is not required, but the wire must not break under a less strain than 2½ times its weight, in pounds per mile.

3. Tests for ductility should be made as follows: The piece of wire will be gripped by two vises, 6 in. apart, and twisted; the full number of twists must be distinctly visible on the 6-in. piece between the vises, and the number of twists must not be less than 15.

4. The weight per mile for the different gauge wires must be: for No. 4 B. W. G., 730 lb.; No. 6, 540 lb.; No. 8, 380 lb.; No. 9, 320 lb.; No. 10, 250 lb.; or as near these figures as practicable.

5. The electrical resistance of the wire, in ohms per mile, at a temperature of 68° F., must not exceed the quotient arising from dividing the constant number 4,800 by the

Sample Mark and B. W. G. No.	Mechanical					Electrical	
	Weight per Mile Pounds	Percentage of Elongation	Number of Twists That 6 In. Will Stand	Actual Breaking Stress Pounds	Relative Breaking Stress	Percentage Conductivity	Resistance per Mile in Ohms, at 60° F.
E. B. B. 12	190.83	11.50	15.00	417.50	11,552.20	14.40	30.50
E. B. B. 8	381.66	17.70	26.50	937.50	12,930.50	17.30	12.67
E. B. B. 11	222.64	17.20	21.50	577.50	13,639.40	15.60	24.20
151 9½	282.80	10.00	26.50	770.00	14,375.90	21.90	16.10
E. B. B. 10	254.44	17.70	28.50	697.50	14,478.10	17.80	18.42
146 9½	287.50	16.00	29.00	832.50	15,288.86	21.90	16.10
E. B. B. 6	508.88	11.40	21.50	1,587.50	16,462.40	17.70	9.21
E. B. B. 9	318.05	19.30	17.50	1,007.50	16,725.10	16.90	15.54
Nashua 8	381.66	15.10	26.50	1,535.00	21,183.00	14.70	15.00
M. S. plain 6	528.00	10.40	19.50	2,137.50	21,375.00	13.50	11.78
443 8	378.10	10.00	31.00	1,635.00	22,301.40	16.50	16.10
A. H. 9½	293.50	16.00	27.50	1,257.50	22,635.00	15.10	22.70

DIMENSIONS AND RESISTANCE OF IRON WIRE

No. B. W. G.	Diameter in Mils = d	Area in Circular Mils = d^2	Weight in Pounds		Breaking Strength in Pounds		Resistance per Mile at 68° F.		
			1,000 Ft.	1 Mi.	Iron	Steel	E. B. B.	B. B.	Steel
0	340	115,600	304.0	1,607	4,821	9,079	2.93	3.42	4.05
1	300	90,000	237.0	1,251	3,753	7,068	3.76	4.40	5.20
2	284	80,656	212.0	1,121	3,363	6,335	4.19	4.91	5.80
3	259	67,081	177.0	932	2,796	5,268	5.04	5.90	6.97
4	238	56,644	149.0	787	2,361	4,449	5.97	6.99	8.26
5	220	48,400	127.0	673	2,019	3,801	6.99	8.18	9.66
6	203	41,209	109.0	573	1,719	3,237	8.21	9.60	11.35
7	180	32,400	85.0	450	1,350	2,545	10.44	12.21	14.43
8	165	27,225	72.0	378	1,134	2,138	12.42	14.53	17.18
9	148	21,904	58.0	305	915	1,720	15.44	18.06	21.35
10	134	17,956	47.0	250	750	1,410	18.83	22.04	26.04
11	120	14,400	38.0	200	600	1,131	23.48	27.48	32.47
12	109	11,881	31.0	165	495	933	28.46	33.30	39.36
13	95	9,025	24.0	125	375	709	37.47	43.85	51.82
14	83	6,889	18.0	96	288	541	49.08	57.44	67.88
15	72	5,184	13.7	72	216	407	65.23	76.33	90.21
16	65	4,225	11.1	59	177	332	80.03	93.66	110.70
17	58	3,364	8.9	47	141	264	100.50	120.40	139.00
18	49	2,401	6.3	33	99	189	140.80	164.80	194.80

IRON AND STEEL WIRE

(Weight per Mile-Ohm)

Name of Wire	Weight per Mile-Ohm	
	Roebling's Sons Co.	Washburn & Moen
Extra Best Best	4,700	5,000
Best Best	5,500	6,200
Best	6,000	
Steel	6,500	6,500

COMPARISON OF PROPERTIES OF COPPER AND ALUMINUM

Properties	Aluminum	Copper
Conductivity (for equal sizes)	.54 to .63	1
Weight (for equal sizes)	.33	1
Weight (for equal length and resistance)	.48	1
Price—aluminum, 29c.; copper, 16c.; (bare line wire)	1.81	1
Price—(Equal resistance and length, bare line wire)	.868	1
Temperature coefficient per degree F.	.002138	.002155
Resistance of mil-foot (20° C.)	18.73	10.5
Specific gravity	2.5 to 2.68	8 89 to 8.93
Tensile strength (hard-drawn) per square inch	40,000	60,000
Tensile strength (for equal weight and resistance)	58,000	60,000
Coefficient of expansion per degree F.	.0000231	.0000093

COMPARATIVE DATA—ALUMINUM AND COPPER

Property	Pure Copper	Aluminum		
		A 0	A 75	A 2
Conductivity	100	62	58	54
Comparative section of equal conductivity	100	156.4	167.0	180.0
Comparative weights of same lengths of equal conductivity	100	47	50.2	54.0

weight of the wire, in pounds per mile. The coefficient .003 will be allowed for each degree F. in reducing to standard temperature

6. The wire must be well galvanized, and be capable of withstanding the following tests: Several samples to be selected at random and immersed in a saturated solution of copper sulphate for 70 sec., then removed and wiped dry and clean; this operation to be repeated three more times and if, then, the wire remains black as after the first immersion, there being no appearance of a copper deposit, the samples are well galvanized. Any appearance of a copper deposit shows that the film of zinc forming the galvanizing covering was too thin and has been removed by combining with the sulphuric acid of the solution and forming zinc sulphate.

ALLOYED WIRE

Phono-electric wire is made by the Bridgeport Brass Company of an alloy containing 98.55% copper, 1.4% tin, and .5% silicon. In its manufacture, the silicon is nearly all slagged off, only .05% remaining. It is claimed to have a tensile strength from 40 to 45% greater than that of hard-drawn copper. Its conductivity is only 40% of pure copper. It is exceedingly tough, as a 6-in. piece of No. 8 will stand 50 complete turns, instead of 30 for hard-drawn copper. It is used for trolley wire and for long telephone-line spans.

RESISTANCE OF PURE ALUMINUM WIRE AT 75° F.*

B. & S. Gauge No.	Ohms per 1,000 Ft.	Ohms per Mile	Feet per Ohm	Ohms per Pound
0000	.08177	.43172	12,229.8	.00042714
000	.10310	.54440	9,699.0	.00067022
00	.13001	.68645	7,692.0	.0010812
0	.16385	.86515	6,245.4	.0016739
1	.20672	1.09150	4,637.35	.0027272
2	.26077	1.37637	3,836.22	.0043441
3	.32872	1.7357	3,036.12	.0069057
4	.41448	2.1885	2,412.60	.010977
5	.52268	2.7597	1,913.22	.017456
6	.65910	3.4802	1,517.22	.027758
7	.83118	4.3885	1,203.12	.044138
8	1.06802	5.5355	964.180	.070179
9	1.32135	6.9767	756.780	.11156
10	1.66667	8.8000	600.000	.17467
11	2.1012	11.0947	475.908	.28211
12	2.6497	13.990	377.412	.44856
13	3.3412	17.642	299.298	.71478
14	4.3180	22.800	231.582	1.1623
15	5.1917	27.462	192.612	1.7600
16	6.6985	35.368	149.286	2.8667
17	8.4472	44.602	118.380	4.5588
18	10.6518	56.242	93.8820	7.2490

19	13.8148	72.942	72.3840	12.192
20	16.938	89.430	59.0406	18.328
21	21.358	112.767	46.8222	29.142
22	26.920	142.138	37.1466	46.316
23	33.962	179.32	29.4522	73.686
24	42.825	226.12	23.3508	117.17
25	54.000	285.12	18.5184	186.28
26	68.113	359.65	14.6814	296.32
27	85.865	453.37	11.6460	485.56
28	108.277	571.70	9.2358	749.02
29	136.535	720.90	7.3242	1,191.0
30	172.17	908.98	5.8087	1,893.9
31	212.12	1,119.98	4.7144	2,941.5
32	273.97	1,445.45	3.6528	4,788.9
33	345.13	1,822.3	2.8974	7,610.7
34	435.38	2,298.8	2.2969	12,109.
35	548.92	2,898.2	1.8218	19,251.
36	692.07	3,654.2	1.4449	30,600
37	872.93	4,609.2	1.1456	48,661.
38	1,100.62	5,811.2	.9086	76,658.
39	1,387.47	7,325.8	.7207	121,881.
40	1,749.50	9,236 8	.5716	193,835.

*Calculated on the basis of Matthiessen's standard, viz.: 1 mi. of pure copper wire of $\frac{1}{10}$ in. diameter equals 13.59 ohms at 15.5° C. or 59.9° F.

RESISTANCE, TENSILE STRENGTH, AND WEIGHT OF ALUMINUM LINE WIRE

No. in B. & S. Gauge	Diameter in Mils d	Circular Mils d^2	Area in Square Inches $\frac{d^2 \times .7854}{1{,}000{,}000}$	Grade A 0		Grade A 75		Grade A 2		Pounds per Mile Sp. Gr. 2.68 Water, 62,355 lb. per Cu. Ft.	Pounds per Mile of Aluminum Having Same Resistance as Copper Wire of Size Given.
				Resistance per 1,000 Ft. at 75° F.	Tensile Strength, Pounds per Square Inch	Resistance per 1,000 Ft. at 75° F.	Tensile Strength, Pounds per Square Inch	Resistance per 1,000 Ft. at 75° F.	Tensile Strength, Pounds per Square Inch		Grade A 75
4	204.31	41,742	.032784	.4012	27,000	.4288	33,000	.4605	40,000	200.90	336.0
5	181.94	33,102	.025998	.5058	27,500	.5408	34,000	.5818	42,000	159.30	266.4
6	162.02	26,250	.020617	.6380	28,000	.6820	35,000	.7325	44,000	126.35	211.4
7	144.28	20,816	.016349	.8044	29,000	.8600	36,000	.9235	46,000	100.21	167.6
8	128.49	16,509	.012966	1.634	30,000	1.105	37,000	1.187	48,000	79.46	133.2
9	114.43	13,094	.010284	1.278	32,000	1.367	39,000	1.468	50,000	62.99	105.4
10	101.89	10,381	.0081532	1.613	33,000	1.724	40,000	1.852	51,000	48.71	83.6
11	90.74	8,234.0	.0064670	2.033	35,000	2.173	41,000	2.335	53,000	39.63	66.3
12	80.81	6,529.9	.0051286	2.565	39,000	2.741	42,000	3.084	55,000	31.43	52.6
13	71.96	5,178.4	.0040671	3.233		3.456		3.712		24.83	
14	64.08	4,106.8	.0031469	4.179		4.467		4.798		19.76	

Silicon- and *aluminum-bronze wires* have high tensile strength and are free from corrosion, thus rendering them especially suitable for guy wires; they resist corrosion fully as well as hard-drawn copper. Some silicon-bronze wires have a tensile strength of 80,000 lb. per sq. in. and are capable of standing 80 twists in a length of 6 in. before breaking. An aluminum-bronze wire showed a strength of 110,000 lb. per sq. in., but its ductility was less than that of the silicon-bronze wire. The low conductivity of bronze wires (not much over 35% that of pure copper, and much lower for some of the alloys) excludes them from use for line wires.

Bronze wires cost about six times as much as either iron or steel. On account of their cost, they are used but very little, if at all, in the United States; on some long lines in Europe, it is quite customary to use bronze wires of some kind.

GERMAN-SILVER WIRE

German silver is an alloy consisting of 18% to 30% nickel and the balance about 4 parts copper to 1 part zinc. Weight of the alloy per cubic foot about 530 lb.; specific gravity, 8.5. Resistance of the 18% alloy at 25° C. 18 times that of copper, and of the 30% alloy about 28 times that of copper. Temperature coefficient from 0° to 100° C. .044% increase of resistance for 1° C. increased temperature. The maximum safe carrying capacity of German-silver wire in spirals in open air for continuous duty is such that the circular mils per ampere varies from about 1,500 in No. 10 wire to about 475 in No. 30. For intermittent duty, the capacity is twice as great.

SIZES OF WIRE FOR TELEPHONE AND TELEGRAPH LINES

Telephone Lines.—No definite rules can be given for choosing the proper wire to be used for overhead telephone lines, but the following wires and sizes will ordinarily answer for the purposes mentioned. For telephone lines in the country and small towns for distances not exceeding 8 mi., No. 14 B. W. G., B. B. galvanized-iron wire may be used; for distances not to exceed 25 mi., No. 12 B. W. G., B. B.

RESISTANCE OF GERMAN-SILVER WIRE

B. & S. G. No.	Resistance per 1,000 Feet International Ohms		B. & S. G. No.	Resistance per 1,000 Feet International Ohms	
	18% Wire	30% Wire		18% Wire	30% Wire
6	7.20	11.21	21	232.92	362.32
7	9.12	14.18	22	295.38	459.48
8	11.54	17.95	23	370.26	575.96
9	14.55	22.63	24	468.18	728.28
10	18.18	28.28	25	590.22	918.12
11	22.84	35.53	26	748.08	1,163.68
12	28.81	44.82	27	937.98	1,459.08
13	36.48	56.75	28	1,191.24	1,853.04
14	46.17	71.82	29	1,481.22	2,304.12
15	58.21	90.55	30	1,891.8	2,942.8
16	72.72	113.12	31	2,388.6	3,715.6
17	93.40	145.29	32	2,955.6	4,597.6
18	118.20	183.87	33	3,751.2	5,835.2
19	145.94	227.02	34	4,764.6	7,411.6
20	184.68	287.28	35	6,031.8	9,382.8

galvanized-iron wire may be used; for distances from 25 to 100 mi., No. 10 B. W. G., B. B. galvanized-iron wire may be used; for distances of 100 mi. and over, hard-drawn copper wire should be used, not smaller than No. 10 B. & S. for 150 mi. and over. The size most generally used on farmers' lines is No. 12 B. B. galvanized-iron wire, weighing about 165 lb. per mi. although No 14 will answer up to about 8 mi.

For small city or town lines, No. 14 B. W. G., B. B. galvanized-iron wire is extensively used; although in towns where cable forms part of the line, steel wire may be used. For lines connected with large city exchanges, hard-drawn copper wire (usually No. 12 B. & S.) is almost always used.

For toll lines not exceeding 75 mi., B. B. galvanized-iron wire, generally No. 10 B. W. G. (but in a few cases No. 8 B. W. G.) is used; from 75 to 150 mi., the E. B. B. grade or hard-drawn copper should be used. For good toll lines of any length, the best practice calls for complete metallic circuits of hard-drawn copper, No. 10 B. & S. up to about 500 mi., and No. 8 B. & S. up to about 1,000 mi.

For interior wiring for telephones, No. 16 or No. 18 B. & S. copper wire should be used—in dry places weather-proof office wire, and in damp places rubber-covered wire.

Telegraph Lines.—The following sizes are those in use for telegraph lines:

No. 10 B. & S. hard-drawn copper and No. 4 B. W. G. galvanized-iron wires are now used on important quadruplex circuits. Formerly, No. 6 B. W. G. galvanized-iron wire was used for this purpose.

No. 6 B. W. G. galvanized-iron wire is used for important circuits between cities.

No. 8 B. W. G. galvanized-iron wire, or No. 12 B. & S. hard-drawn copper wire, is much used for circuits of 400 mi., or less, in length. No. 9 B. W. G. galvanized-iron wire was formerly used for this purpose.

No. 9 B. W. G. galvanized-iron wire was, until recently, the size generally used in the United States. It is now used on short circuits where No. 8 is not considered necessary.

Nos. 10 and 11 B. W. G. galvanized-iron wires are used for still shorter circuits and for railway telegraph, police, fire-alarm, and private lines. No. 12 B. W. G. galvanized-iron wire is also used for these purposes.

Nos. 13 and 14 B. W. G. steel wires are used for short private lines and where strength is especially necessary.

No. 8 B. & S. copper wire should be used for permanent ground wires in terminal telegraph offices

OHM'S LAW

The law governing the flow of current in an electric circuit is known as *Ohm's law*, and may be stated as follows: *The strength of the continuous current in any circuit is directly proportional to the electromotive force in the circuit, and inversely proportional to the resistance of the circuit;* that is, $I=\frac{E}{R}$, from which $R=\frac{E}{I}$, and $E=IR$, where I = current in amperes, E = E. M. F. in volts, and R = resistance in ohms. If there is in the circuit more than one source of electromotive force, the value of the resultant electromotive force must be used in these formulas. Furthermore, if the circuit contains inductance or capacity, the formulas are not applicable to variable- or alternating-currents.

CAPACITY

Capacity (C) is comparable to the capacity of a bottle containing air. The addition of a given amount of air will raise the pressure more or less, and the amount of air required to produce a certain pressure in the bottle may be taken as the measure of the capacity of the bottle. This capacity is analogous to the electrostatic capacity of a condenser, which is measured by the quantity of electricity with which it must be charged in order to raise its electrical potential from zero to unity. The *unit of capacity* is the *farad*. A condenser has a capacity of 1 farad when 1 coulomb is required to raise its potential from zero to 1 volt. Since the farad is very large, its millionth part, or the *microfarad*, is generally used as the practical unit. The microfarad $=\frac{1}{1{,}000{,}000}$, or 10^{-6} farads. Condensers from $\frac{1}{10}$ to 6 micro-

farads capacity are the sizes most commonly used in the United States.

CAPACITY OF CONDENSERS

If a difference of potential of E volts exists across the terminals of a condenser of C farads capacity, then the charge of Q coulombs in the condenser may be calculated from the formula

$$Q=CE$$

from which $$C=\frac{Q}{E}$$

and $$E=\frac{Q}{C}$$

The capacity of a condenser is given by the formula

$$C\text{ (microfarads)}=\frac{885\ Ka}{d10^{10}},$$

in which K is the inductivity of the dielectric between the tin-foil or metal plates; a is the area in square centimeters of all the dielectric sheets actually between and separating the condenser plates; and d is the average thickness in centimeters of the dielectric sheets. If there are n insulating sheets, each of area s, then $a=ns$.

When a and d are given in square inches and inches, respectively, the formula becomes

$$C\text{ (microfarads)}=\frac{2{,}248\ Ka}{d\times 10^{10}}.$$

Condensers in Parallel.—When two or more condensers are connected in parallel, the joint capacity C is equal to the sum of their capacities, that is, $C=C_1+C_2+C_3+\text{etc.}$

Condensers in Series.—When two or more condensers C_1, C_2, C_3, etc. are joined in series, their joint capacity C is equal to the reciprocal of the sum of their reciprocals, that is,

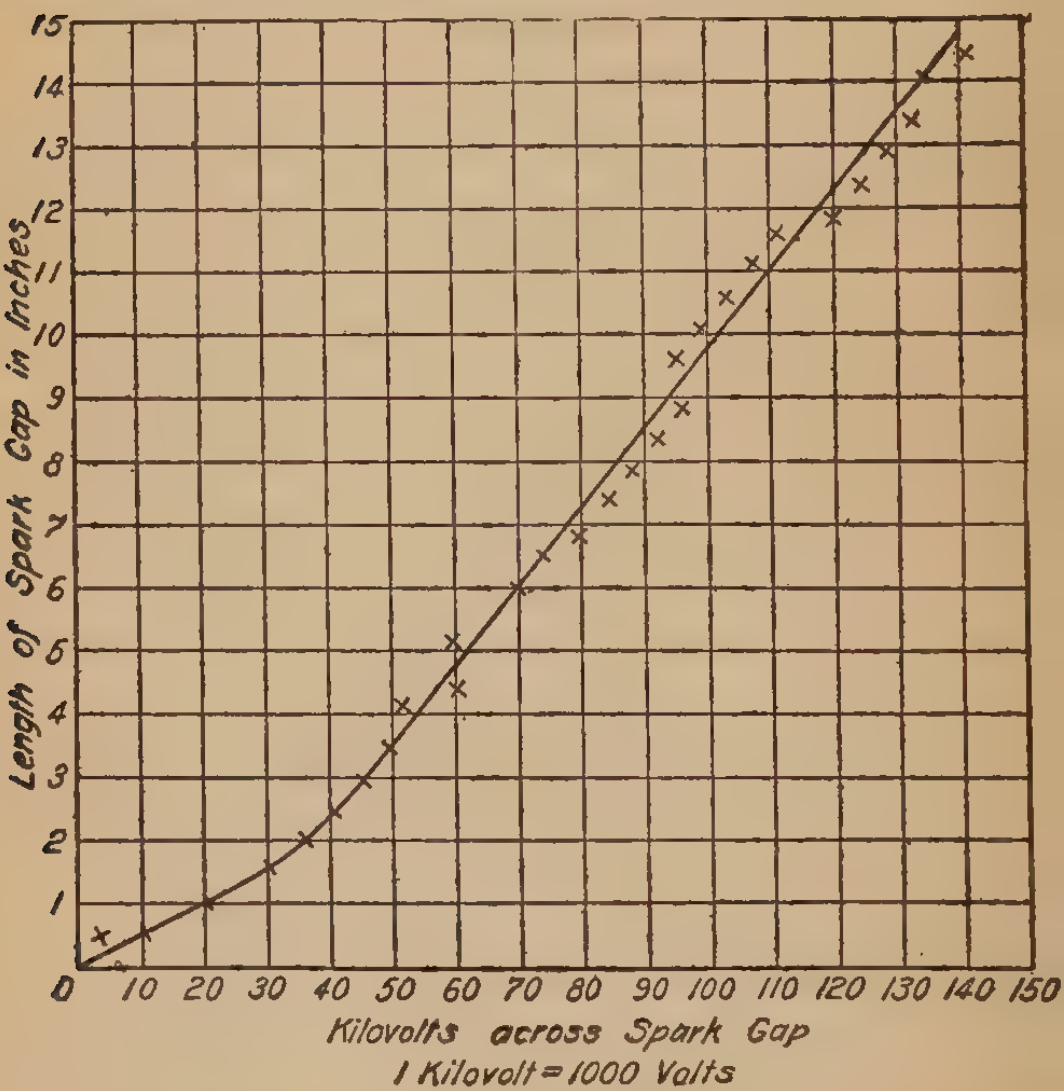
$$C=\frac{1}{\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\text{etc.}}$$

There are as many terms in the denominator as there are condensers connected in series. For example, the capacity of four condensers of 2, 4, 5, and 8 microfarads capacity connected in series is calculated as follows: $\frac{1}{2}+\frac{1}{4}+\frac{1}{5}+\frac{1}{8}=1.075$, and $\frac{1}{1.075}=.93$ microfarad.

INDUCTIVITY

The *inductivity*, or *specific inductive capacity*, of a substance is its *dielectric power*, or ability to convey the influence of an electrified body. Calling the inductivity of dry air at standard atmospheric pressure 1, the inductivity of any other substance is measured by the ratio of the capacity

DIELECTRIC STRENGTH OF AIR



of a condenser when its plates are separated by that substance to the capacity of the same condenser when its plates are separated by the same thickness of dry air. Various methods are used to determine the inductivities of substances and the capacities of condensers, and these methods do not all give the same results. Values obtained by the so-

INDUCTIVITIES OF VARIOUS SUBSTANCES

Material	Inductivity *K*
Air, vacuum at about .001 mm. pressure	.9400
Air, vacuum at about 5 mm. pressure	.9990
Hydrogen, at ordinary pressure	.9997 to 1.00026
Air, at ordinary pressure, standard	1.0000
Carbon dioxide, at ordinary pressure	1.00036 to 1.00095
Olefiant gas, at ordinary pressure	1.0007
Methane	1.0009
Sulphur dioxide, at ordinary pressure	1.0037
Manila paper	1.50
Carbon bisulphide	1.60 to 1.81
Paraffin, clear	1.68 to 2.32
Beeswax	1.86
Paraffin, solid	1.9936* to 2.32
Resin	1.77 to 2.55
Ozokerite	2.00
Petroleum	2.03 to 2.42
Ebonite	2.05* to 3.15
Turpentine	2.15 to 2.43
India rubber, pure	2.22 to 2.497
Sulphur	2.24 to 3.84
Gutta percha	2.46* to 4.20
Shellac	2.74* to 3.60
Olive and neat's-foot oils	3.00 to 3.16
Sperm oil	3.02 to 3.09
Glass	3.013* to 3.258*
Mica	4.00 to 8
Porcelain	4.38
Quartz	4.50
Flint glass, very light	6.57
Flint glass, light	6.85
Flint glass, very dense	7.40
Flint glass, double extra dense	10.10

*Results obtained by instantaneous methods.

called instantaneous methods are invariably lower than values obtained by the slower charge and discharge methods.

DIELECTRIC STRENGTH

The *dielectric strength* of an insulating substance is the maximum difference of potential that it will stand without being punctured. It is determined by placing a thin layer of the substance between two metal electrodes, and increasing the difference of potential between the electrodes by small steps until a spark passes through the dielectric; the difference of potential in volts preceding that which punctures the insulation is the maximum strength of the dielectric.

The curve on page 122 shows the dielectric strength of air, as determined by C. P. Steinmetz, with a frequency of 125 cycles per sec., using needle points $2\frac{1}{2}$ in. long.

INDUCTANCE

Inductance, or the *coefficient of self-induction* L, is the ratio between the total induction through a circuit to the current producing it. The unit of inductance is the *henry*. An inductance of 1 henry exists in a circuit when a current changing at a rate of 1 ampere per sec. induces an electromotive force of 1 volt in the circuit. As the henry is quite large, the one-thousandth part of it, or the millihenry, is frequently used. The millihenry $= \frac{1}{1000}$ or 10^{-3} henry.

WORK AND POWER

Work, or *energy*, is expended in a circuit or conductor when a current of electricity flows through it. The unit of electrical work or energy is called the *joule*, after an eminent English scientist. If E is the electromotive force, or difference of potential, in volts that causes Q coulombs of electricity to flow through a circuit, the work expended in joules is

$$J = E \times Q$$

If an electromotive force, or difference of potential, of E volts causes a current of I amperes to flow for t seconds through a resistance of R ohms, then

$$J = EIt$$
$$J = \frac{E^2t}{R}$$
$$J = I^2Rt$$

The joule may be defined as the work done when 1 ampere flows for 1 second through a resistance of 1 ohm.

The energy used in forcing current through a resistance is converted into heat as follows:

4.2 joules = 1 small calorie
1 joule = .24 small calorie

The *watt-hour* is an extensively used unit of work. Watt-hours equal the product of the average number of watts and the number of hours during which they are expended. One *kilowatt-hour* = 1,000 watt-hours, or the product of the average number of kilowatts and the number of hours. Although five figures are given in most of the values in the accompanying table, it is rarely necessary to use more than three figures, and in very many cases two figures are sufficient. For instance, it is usually sufficient to use 1 calorie (gram-degree-C.) = 4.2 joules, or, to be a little more exact, 1 calorie = 4.19 joules. This table was calculated on the basis of 1 B. T. U. being equal to 778 ft.-lb., and the acceleration of gravity g was taken as equal to 981 cm. per sec. per sec.

Power (P), which is the rate at which work is done, is equal to the work divided by the time, and may be calculated by any one of the following formulas.

$$P = IE = I^2R = \frac{E^2}{R} = \frac{J}{t}$$

If I is in amperes, R in ohms, E in volts, J in joules, and t in seconds, P is in watts.

The *watt*, or unit of electric power, is equal to 1 joule per sec. It is the rate at which work is expended when 1 ampere flows through a resistance of 1 ohm. The watt is too small a unit for convenient use in many cases, so that the kilowatt (K. W.), or 1,000 watts, is frequently used.

1 H. P. equals 746 watts; therefore, $\text{H. P.} = \frac{P \text{ (in watts)}}{746}$

or $$\text{H. P.} = \frac{P \text{ (in kilowatts)}}{.746}$$

NUMBER OF VOLTS REQUIRED TO PRODUCE A SPARK BETWEEN BALLS IN AIR

Length of Spark Gap in		Diameter of the Balls		
Centimeters	Inches	1 Cm. = .3937 In.	2 Cm. = .787 In.	6 Cm. = 2.36 In.
		Volts	Volts	Volts
.02	.0079	1,560	1,530	
.04	.0157	2,460	2,430	
.06	.0236	3,300	3,240	
.08	.0315	4,050	3,990	
.10	.0394	4,800	4,800	4,500
.20	.0787	8,400	8,400	7,800
.30	.1181	11,400	11,400	10,800
.40	.1575	14,400	14,400	13,500
.50	.1969	17,100	17,100	16,500
.60	.2362	19,500	19,800	19,500
.70	.2756	21,600	22,500	22,500
.80	.3150	23,400	24,900	26,100
.90	.3543	24,600	27,300	29,000
1.00	.3937	25,500	29,100	32,700

DIELECTRIC STRENGTH OF VARIOUS SUBSTANCES

(*Macfarlane and Pierce*)

Substance	Strength in Volts per Centimeter
Oil of turpentine	94,000
Paraffin oil	87,000
Olive oil	82,000
Paraffin (melted)	56,000
Kerosene oil	50,000
Paraffin (solid)	130,000
Beeswaxed paper	540,000
Air (thickness 5 cm.)	23,800
CO^2 (thickness 5 cm.)	22,700
Oxygen (thickness 5 cm.)	22,200
Hydrogen (thickness 5 cm.)	15,100
Coal gas (thickness 5 cm.)	22,300

DIELECTRIC STRENGTH OF VARIOUS SUBSTANCES

(*Parshall and Hobart*)

Substance	Thickness in Inches	Puncturing Voltage	Volts per $\frac{1}{1000}$ In.
Composite sheets of mica and paper prepared so as to be moisture-proof	.005	3,600 to 5,860	
	.007	7,800 to 10,800	
	.009	8,800 to 11,400	
	.011	11,600 to 14,600	
Leatheroid	$\frac{1}{64}$ or .0156	5,000	320
	$\frac{1}{32}$ or .0313	8,000	256
	$\frac{3}{64}$ or .0469	12,000	256
	$\frac{1}{16}$ or .0625	15,000	240
	$\frac{1}{8}$ or .125	15,000	120
	$\frac{3}{16}$ or .188	6,000	32
	$\frac{1}{4}$ or .25	6,000	24
Vulcanized fiber	$\frac{1}{8}$ or .125 to 1	about 10,000	
Hard rubber			500
Kiln-dried maple and other similar woods	1	10,000 to 20,000	
Vulcabeston	$\frac{1}{2}$	10,000	
Red pressboard	.03	10,000	
Red rope paper	.01	1,000	
Manila paper	.003	400	
Oiled cambric	.007	2,500 to 4,500	
Oiled cotton	.003	6,300 to 7,000	
Oiled paper	.004	3,400 to 4,800	
	.010	5,000	
Mica		1 to 2.1×10^6 per mm.	

RELATION BETWEEN UNITS OF WORK

Name of Unit	Ergs	Joules	Kilowatt-Hours	Calories	Foot-Pounds	B. T. U.
1 erg	1	$\frac{1}{10^7}$	$\frac{2,778}{10^{17}}$	$\frac{23,882}{10^{12}}$	$\frac{73,734}{10^{12}}$	$\frac{94,774}{10^{15}}$
1 joule	10^7	1	$\frac{2,778}{10^{10}}$	.23882	.73734	$\frac{94,774}{10^8}$
1 kilowatt-hour	36×10^{12}	36×10^5	1	859,770	2,654,400	3,411.8
1 calorie (gram-deg. C.)	41,872,000	4.1872	$\frac{11,631}{10^{10}}$	1	3.0873	$\frac{39,683}{10^7}$
1 foot-pound	13,562,000	1.3562	$\frac{37,673}{10^{11}}$	.32390	1	.001285
1 British thermal unit (lb.-deg. F.)	$10,551\times10^6$	1,055.1	$\frac{29,310}{10^8}$	252.00	778	1

MAGNETISM

MAGNETIC QUANTITIES

Strength of Pole (m).—A magnetic pole of unit strength is one that repels with a force of 1 dyne another similar and equal pole when placed 1 cm. from it.

Magnetic Moment ($\mathfrak{M}$).—The magnetic moment of a magnet is equal to the product of the strength m of one of its poles and the distance l between the poles. That is $\mathfrak{M} = m \times l$.

Intensity of Magnetization ($\mathfrak{J}$).—The intensity of magnetization is equal to the strength m of a magnetic pole divided by its area A; that is, $\mathfrak{J} = \frac{m}{A}$.

The *intensity of magnetic field*, *field density*, or *magnetizing force* $\mathfrak{H}$ at any point is measured by the force with which the field acts on a unit pole placed at that point. A unit field, called a *gauss*, acts with a force of 1 dyne on a unit pole, and is represented by 1 line of force, or 1 *maxwell*, per sq. cm. A field having an intensity of 5 lines of force per sq. cm. may be called a field of 5 maxwells per sq. cm., or simply a field of 5 gausses. The number of lines of force, or maxwells per unit area of a magnetic substance is variously called its *magnetic induction*, *flux density*, *magnetic density*, or simply *magnetism*, and is represented by $\mathfrak{B}$ when the unit area is 1 sq. cm. or by **B** when the unit area is 1 sq. in.

Magnetic flux, or *total induction*, usually designated by the Greek letter Φ (phî), is the total number of lines of force threading a magnetic circuit, and is equal to the product of the magnetic density and the cross-sectional area; that is,

$$\Phi = \mathfrak{B}A$$

If $\mathfrak{B}$ is expressed in lines of force per square centimeter, or gausses, then A must be in square centimeters; and if **B** is in lines of force per square inch, A must be in square inches.

Magnetic Permeability (μ).—Magnetic permeability is the ratio between the flux density $\mathfrak{B}$ and the field intensity $\mathfrak{H}$; that is, if the flux density through a solenoid is $\mathfrak{H}$

MAGNETIC QUALITIES OF ANNEALED SHEET IRON

Magnetic Density per		Magnetizing Force per		Ampere-Turns per		Permeability
Square Centimeter $\mathfrak{B}$	Square Inch **B**	Square Centimeter $\mathcal{H}$	Square Inch **H**	Centimeter Length $\frac{IT}{l}$	Inch Length $\frac{IT}{1}$	μ
1,550	10,000	2.480	16	1.973	5.011	625.0
3,100	20,000	3.565	23	2.836	7.204	869.6
4,650	30,000	4.340	28	3.452	8.770	1,071.4
6,200	40,000	5.115	33	4.069	10.34	1,212.1
7,750	50,000	6.510	42	5.179	13.15	1,190.4
9,300	60.000	8.215	53	6.535	16.60	1,132.0
10,075	65,000					
10,850	70,000	10.54	68	8.384	21.30	1,029.4
12,400	80,000	14.57	94	11.59	29.44	851.0
13,950	90,000	21.39	138	17.02	43.22	652.2
15,500	100,000	33.17	214	26.39	67.02	467.3
16,275	105,000					
17,050	110,000	57.97	374	46.11	117.14	294.1
17,825	115,000					
18,600	120,000	112.38	725	89.39	227.07	165.5
19,375	125,000	166.63	1,057	132.55	346.69	116.3

MAGNETIC QUALITIES OF UNANNEALED CAST STEEL

Magnetic Density per		Magnetizing Force per		Ampere-Turns per		Permeability
Square Centimeter $\mathfrak{B}$	Square Inch **B**	Square Centimeter $\mathfrak{H}$	Square Inch **H**	Centimeter Length $\frac{IT}{l}$	Inch Length $\frac{IT}{1}$	μ
1,550	10,000	2.790	18	2.219	5.638	555.5
3,100	20,000	4.340	28	3.452	8.770	714.3
4,650	30,000	5.425	35	4.312	10.96	857.1
6,200	40,000	6.665	43	5.302	13.47	930.2
7,750	50,000	8.370	54	6.658	16.91	925.9
9,300	60,000	11.16	72	8.878	22.55	833.3
10,075	65,000					
10,850	70,000	15.35	99	10.85	31.01	707.1
12,400	80,000	22.63	146	18.00	45.73	547.3
13,950	90,000	34.88	225	27.74	70.47	400.0
15,500	100,000	58.13	375	46.24	117.45	266.6
16,275	105,000					
17,050	110,000	113.15	730	90.01	228.64	150.7
17,825	115,000	157.33	1,015	125.15	317.90	113.3

MAGNETIC QUALITIES OF WROUGHT-IRON FORGINGS

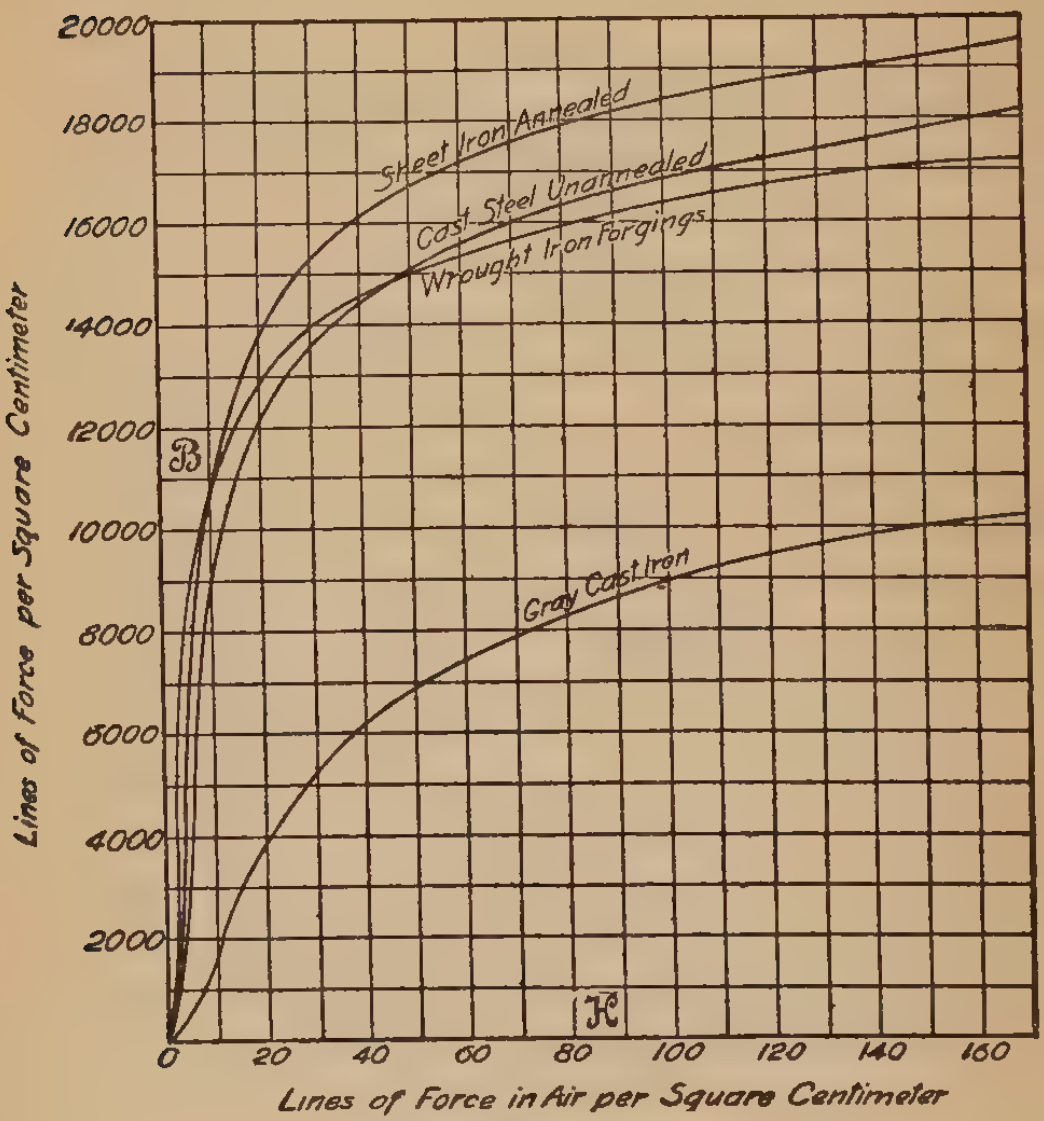
Magnetic Density per		Magnetizing Force per		Ampere-Turns per		Permeability
Square Centimeter $\mathfrak{B}$	Square Inch **B**	Square Centimeter $\mathfrak{H}$	Square Inch **H**	Centimeter Length $\frac{IT}{l}$	Inch Length $\frac{IT}{1}$	μ
1,550	10,000	1.860	12	1.480	3.758	833.3
3,100	20,000	2.325	15	1.850	4.698	1,333.3
4,650	30,000	2.790	18	2.219	5.638	1,595.7
6,200	40,000	3.565	23	2.836	7.204	1,739.1
7,750	50,000	4.650	30	3.699	9.396	1,666.6
9,300	60,000	6.820	44	5.425	13.78	1,363.6
10,075	65,000					
10,850	70,000	10.08	65	8.015	20.36	1,076.9
12,400	80,000	16.12	104	12.82	32.57	769.2
13,950	90,000	31.00	200	24.66	62.64	450.0
15,500	100,000	66.05	430	53.02	134.68	232.6
16,275	105,000	97.65	630	77.68	197.32	166.6
17,050	110,000	160.43	1,035	127.62	324.16	106.3

MAGNETIC QUALITIES OF GRAY CAST IRON

Magnetic Density per		Magnetizing Force per		Ampere-Turns per		Permeability
Square Centimeter $\mathfrak{B}$	Square Inch **B**	Square Centimeter $\mathfrak{H}$	Square Inch **H**	Centimeter Length $\frac{IT}{l}$	Inch Length $\frac{IT}{1}$	μ
1,550	10,000	9.92	64	7.891	20.04	156.3
3,100	20,000	16.28	105	12.95	32.89	190.5
4,650	30,000	25.42	164	20.22	51.36	182.9
6,200	40,000	40.61	262	32.30	82.06	152.9
7,750	50,000	66.65	430	53.02	134.68	116.3
9,300	60,000	112.29	718	88.53	224.49	83.6
10,075	65,000	159.65	1,030	127.0	322.60	63.1

when the core consists of air, and is $\mathfrak{B}$ when the core consists of iron, the permeability of the iron is

$$\mu = \frac{\mathfrak{B}}{\mathfrak{H}} = \frac{\mathbf{B}}{\mathbf{H}}$$

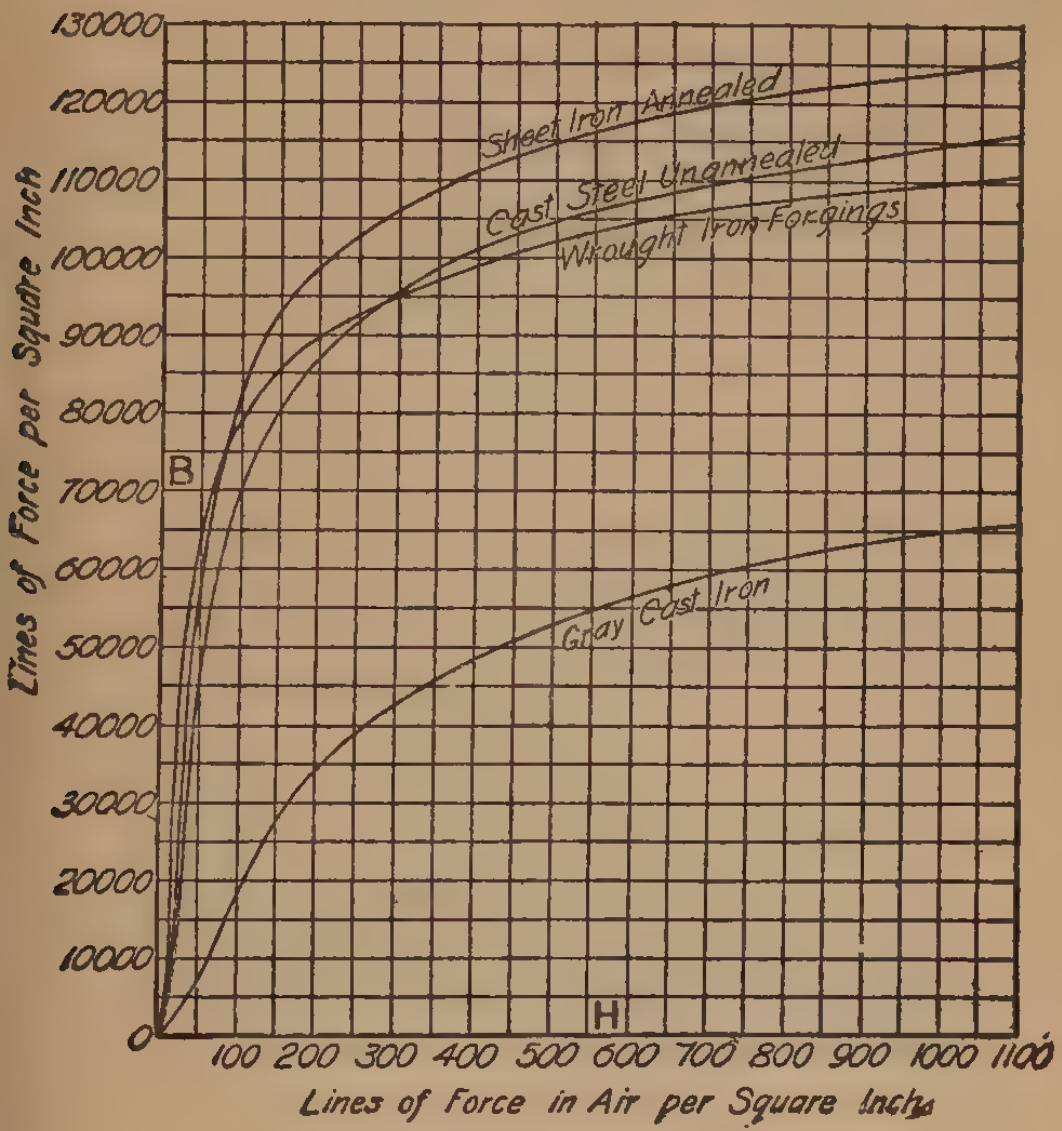


$\mathfrak{B}$–$\mathfrak{H}$ CURVES

Magnetomotive force $\mathfrak{F}$ (sometimes written M. M. F.) for the unit of which the name *Gilbert* has been proposed is the total magnetizing force produced by a coil of T turns through which a current of I amperes is flowing. The magnetomotive force

$$\mathfrak{F} = \frac{4\pi I T}{10} = 1.257\, IT$$

Reluctance $\mathcal{R}$, for the unit of which the name *oersted* has been proposed, is the magnetic resistance, or opposition, offered by a substance to the passage of magnetic flux. Unit magnetomotive force will produce unit flux through



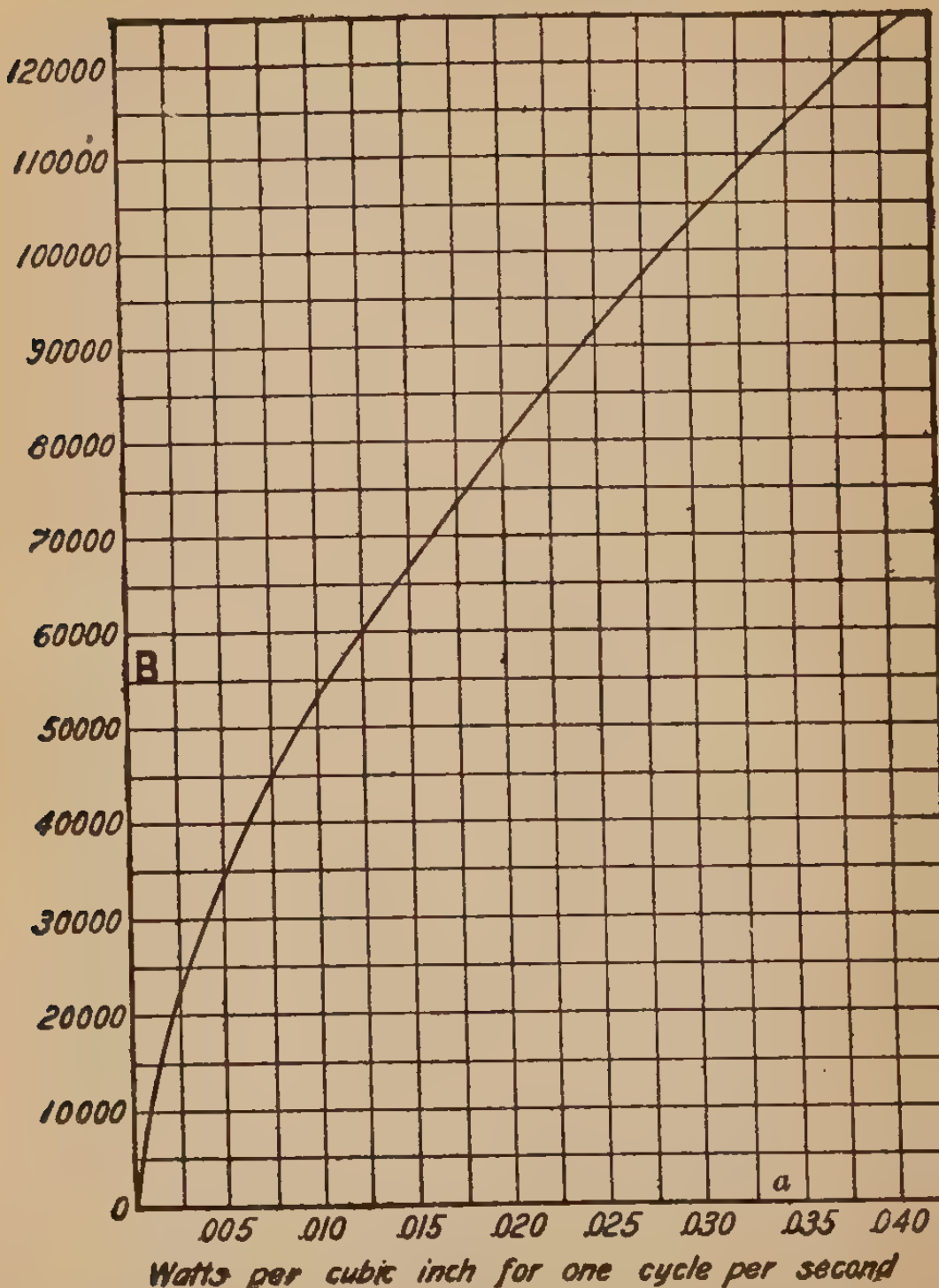
B H CURVES

unit reluctance. A cubic centimeter of a perfectly non-magnetic substance, such as air, has unit reluctance.

HYSTERESIS

Hysteresis may be defined as the tendency of a magnetic substance to persist in any magnetic state that it may have acquired. When an alternating or variable current flows

HYSTERESIS LOSS AT ONE CYCLE PER SECOND AT VARIOUS FREQUENCIES



in a coil around iron, some work is expended due to t
hysteresis of the iron; this work appears as heat in the iro

If a is the power in watts expended in 1 cu. in. of iron for 1 cycle per sec.; $\mathbf{V}$, the volume of iron in cubic inches; n, the number of cycles per second; and P, the total watts expended in hysteresis; then,

$$P = a\mathbf{V}n$$

Obtain the value of a from the curve given on page 136 for any given density $\mathbf{B}$.

The Steinmetz formula for the power in watts lost in hysteresis is

$$P = \frac{kV\mathfrak{B}^{1.6}n}{10^7}$$

where V is the volume in cubic centimeters and $\mathfrak{B}$ is the induction per square centimeter.

The constant k will vary a great deal, depending on the quality of the iron. A fair value for k for annealed sheet iron and steel, such as used in dynamo and motor armatures, is .0035; for gray cast iron .013; and for cast steel, .003.

The total hysteresis loss in watts in iron, where the dimensions are given in inches, is very nearly

$$P = \frac{.83k\mathbf{B}^{1.6}\mathbf{V}n}{10^7}$$

EDDY-CURRENT LOSS

(From Parshall and Hobart)

In sheet iron not over .025 in. thick, the eddy-current loss should theoretically conform to the formula

$$W = 1.5t^2n^2\mathbf{B}^2 \times 10^{-10}$$

where W = watts per pound of iron at 0° C.;
t = thickness of iron, in inches;
n = number of cycles per second;
$\mathbf{B}$ = number of lines of force per square inch.

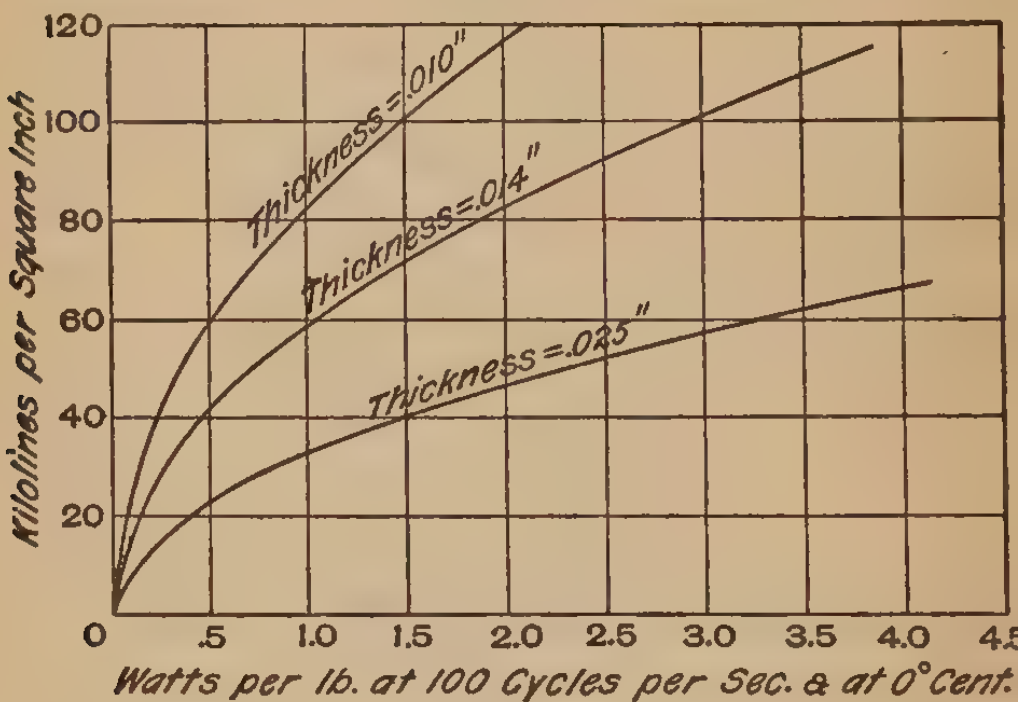
The loss decreases .5% per degree C. increase of temperature. The formula holds for iron whose specific resistance is 10 microhms per cm. cube at 0° C. and whose specific weight is .282 lb. per cu. in. For thicknesses greater than .025 in., the results given by the above formula are greatly modified. The curves in the accompanying figure show eddy-current losses in various thicknesses of sheet iron.

LAWS OF MAGNETIC CIRCUIT

The total magnetic flux in a circuit is directly propor tional to the magnetomotive force acting in the circui and inversely proportional to the reluctance of the circuit; o

$$\Phi = \frac{\mathcal{F}}{\mathcal{R}}$$

If Φ is the flux in maxwells, then $\mathcal{F}$ will be the magneto motive force in C. G. S. units, or gilberts, and $\mathcal{R}$ will b the reluctance in C. G. S. units, or oersteds.



The reluctance of a magnetic circuit is directly proportiona to the length of the circuit, and inversely proportional t the product of the area of the cross-section of the circu and the permeability, or

$$\mathcal{R} = \frac{l}{A\mu}$$

If l and A are in centimeters and square centimeter respectively, $\mathcal{R}$ will be in C. G. S units; if in inches an square inches, the reluctance will be in units to which n name has been given. Since for air and all other non magnetic substances $\mu = 1$, the reluctance $\mathcal{R} = \frac{1}{A}$. In

complex magnetic circuit, the total reluctance is equal to the sum of the reluctances of all the parts.

The magnetomotive force due to an electromagnetic solenoid is directly proportional to the current and to the number of turns in the solenoid; that is,

$$\mathcal{F} = \mathcal{H}l = 1.257IT$$

$$\mathbf{H}\,1 = 3.192IT$$

In which l must be expressed in centimeters and 1 in inches. The field density (in air) produced inside a long solenoid, and approximately inside any coil, whose length is large compared with its diameter, can be determined by the preceding formulas. From the same formulas can be determined the ampere-turns IT required to produce a given field density $\mathcal{H}$ or $\mathbf{H}$ inside a coil whose length is known. The field density multiplied by the average area of the coil gives the total number of lines threading the coil when it contains no iron. If iron is introduced, it is necessary to multiply the field density by the permeability of the iron for that particular field density, and then by the sectional area of the iron, in order to get the total flux threading the iron.

Since $\mathcal{H}l = 1.257IT.$, $IT = .796\mathcal{H}l$, where l is in centimeters; and for a given magnetizing force in a complex magnetic circuit, the number of ampere-turns is

$$IT = .796\mathcal{H}_1 l_1 + .796\mathcal{H}_2 l_2 + .796\mathcal{H}_3 l_3 + \text{etc.},$$

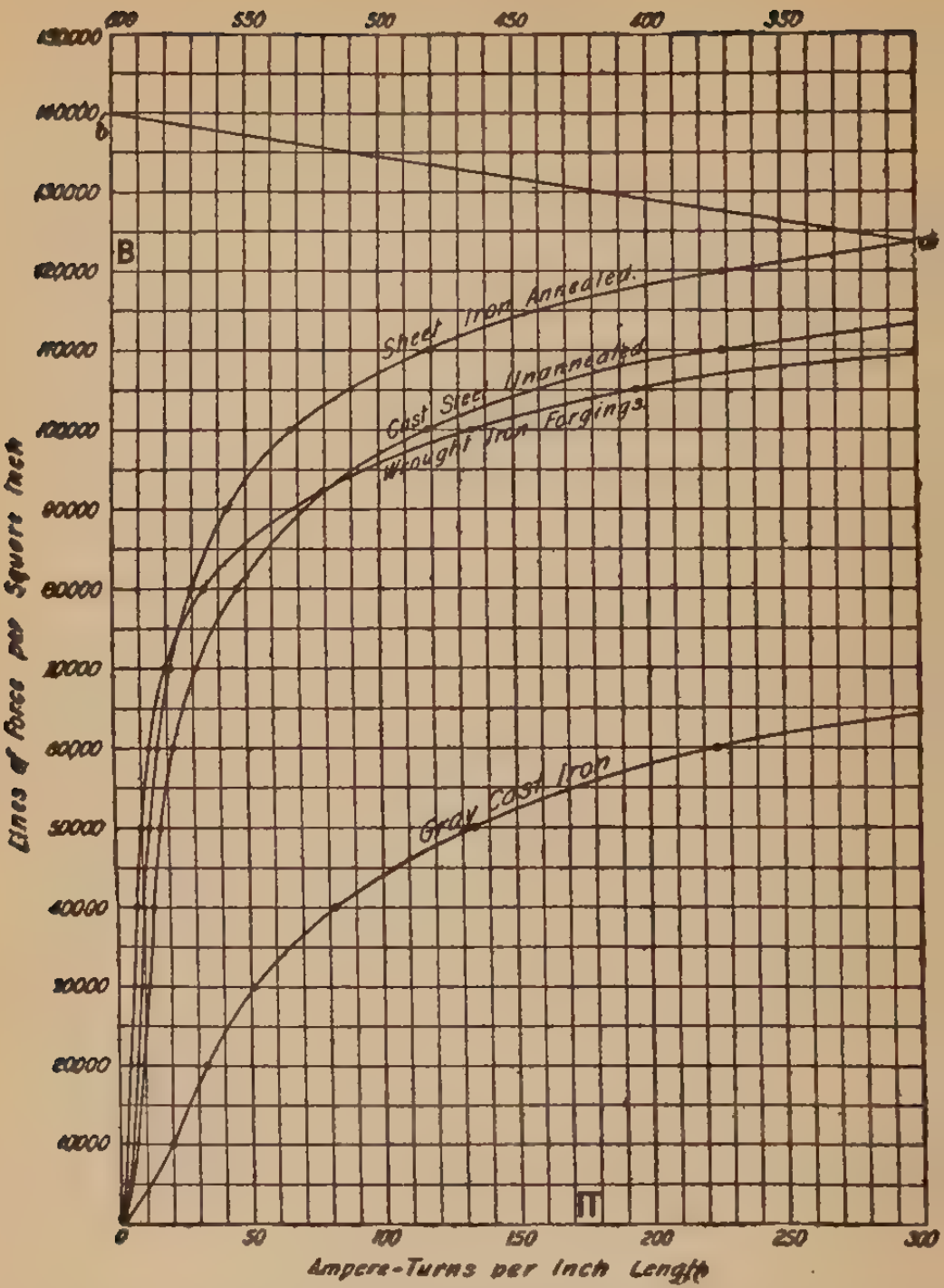
or, when the dimensions are in inches,

$$IT = .313\mathbf{H}_1 1_1 + .313\mathbf{H}_2 1_2 + .313\mathbf{H}_3 1_3 + \text{etc.}$$

The following ampere-turn curves are plotted respectively with $\mathcal{B}$ and $\mathbf{B}$ as ordinates and $.796\mathcal{H}$ and $.313\mathbf{H}$ as abscissas. For a given density, find from the curve the corresponding abscissa which multiplied by the length will give the ampere-turns required for that part of the circuit. The sum of the ampere-turns for each part will give the total number of ampere-turns required.

AMPERE-TURN CURVE—ENGLISH MEASURES

To reduce the length of the curve for sheet iron, the portion b for densities greater than 123,000 per sq. in. is plotted backwards; for example, a density of 125,000 lines per sq. in. requires 325 ampere-turns per in.



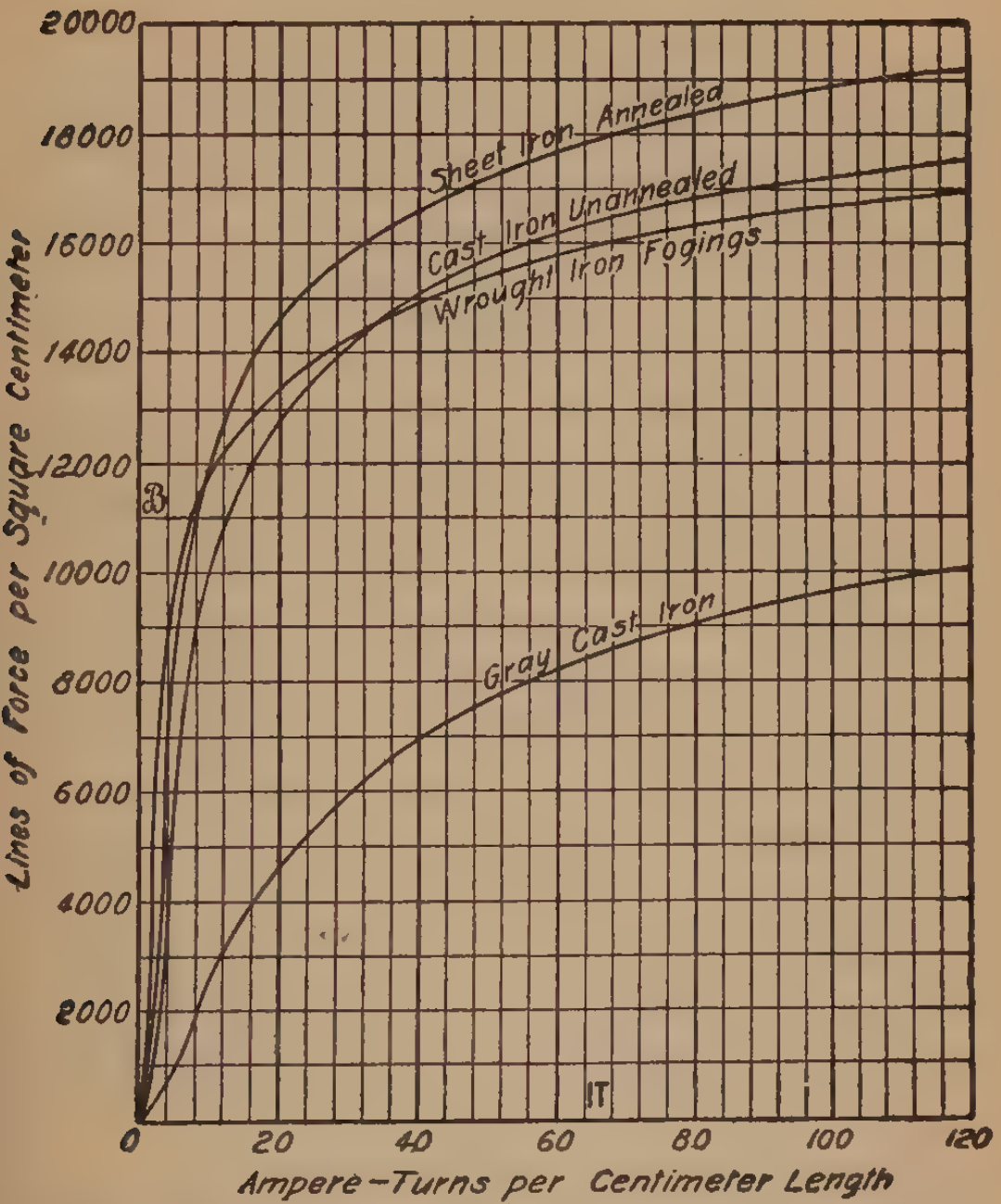
INDUCTION

The electromotive force E in volts generated in a conducto cutting Φ lines of force in t seconds may be computed by th formula

$$E = \frac{\Phi}{10^8 t}$$

Self-Induction.—A coil has 1 C G. S. unit of inductance when 1 C G. S. unit of current flowing through 1 turn pro-

AMPERE-TURN CURVE—METRIC MEASURES



duces 1 line of force. If I is the current in amperes, T the number of turns in a coil, Φ the number of lines of force due to the coil, then the inductance of the coil in henrys is

$$L = \frac{\Phi T}{10^8 I}$$

The inductance in henrys of a coil containing no iron may be computed by the formula

$$L=\frac{4\pi T^2 A}{10^9 l}$$

in which T is the number of turns in the coil, A is its mean area in square centimeters, and l is its length in centimeters. For a cylindrical coil whose mean area is πr^2, the formula reduces to

$$L=\frac{3{,}948 r^2 T^2}{10^{11} l}$$

If the radius and the length of the coil are given in inches, then the inductance in henrys is similar to r

$$L=\frac{10{,}028 r^2 T^2}{10^{11} l}$$

These two formulas are strictly true only for a long coil in which the length is twenty or more times the diameter, and the depth of winding is small compared to the mean radius. However, they may be used to determine approximately the inductance of any ordinary solenoid containing no magnetic material. A formula for the inductance in C. G. S. units of coils having any number of layers and said by L. Cohen to be exact to $\frac{1}{2}$ of 1 per cent., even for short solenoids whose length is twice the diameter and increasing in accuracy as the ratio of length to diameter increases, is as follows: $L=$

$$4\pi^2 n^2 m\left\{\frac{2a_0^4+a_0^2 l^2}{\sqrt{a_0^2+l^2}}-\frac{8a_0^3}{3\pi}\right\}+8\pi^2 n^2\left\{[(m-1)a_1^2+(m-2)a_2^2 + \text{- - -}][\sqrt{a_1^2+l^2}-\tfrac{7}{8}a_1]+\tfrac{1}{2}[m(m-1)a_1^2+(m-1)(m-2)a_2^2 +(m-2)(m-3)a_3^2+\text{- - -}]\left[\frac{a_1 r_1}{\sqrt{a_1^2+l^2}}-r\right]\right\}$$

in which m is the number of layers; a_0, the mean radius of the solenoid; a_1, a_2, a_3, etc., the mean radii of the various layers; l, the length of solenoid; r, the radial distance between two consecutive layers; n, the number of turns per unit length; all dimensions are in centimeters. For a solenoid whose length is at least four times its diameter, the last formula reduces to

$$L = 4\pi^2 n^2 m^2 \left[\frac{2a_0^4 + a_0^2 l^2}{\sqrt{4a_0^2 + l^2}} - \frac{8a_0^3}{3\pi}\right] + 8\pi^2 n^2 \left\{[(m-1)a_1^2 + (m-2)a_2^2 + \text{- - -}][\sqrt{a_1^2 + l^2} - \tfrac{7}{8}a_1]\right\}$$

For a single layer the first formula reduces to

$$L = 4\pi^2 n^2 \left[\frac{2a^4 + a^2 l^2}{\sqrt{4a^2 + l^2}} - \frac{8a^3}{3\pi}\right]$$

If the solenoid contains magnetic material the inductance given by these formulas must be multiplied by the permeability μ of the magnetic material at the density to which the coil magnetizes the iron.

The mutual inductance between two coils in henrys is

$$M = \frac{\Phi T}{10^8 I}$$

RULES FOR DIRECTION OF CURRENT AND MOTION

Rule.—*If the current in a conductor is flowing from south to north, and a compass is placed under the conductor, the north end of the needle will be deflected to the west; if the compass is placed over the conductor, the north end of the needle will be deflected to the east.*

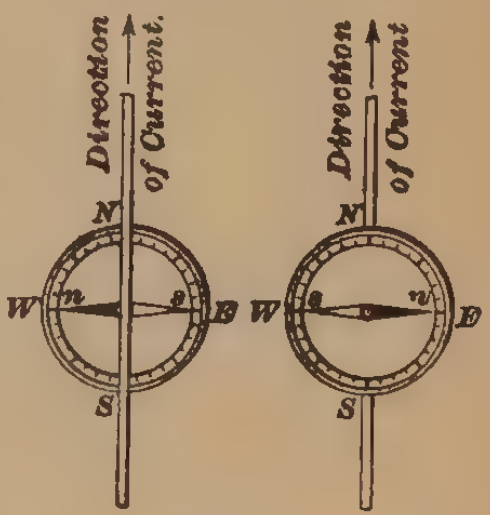


FIG. 1

To determine the polarity of an electromagnetic solenoid: In looking at the end of a solenoid, if an electric current flows in it clockwise, the end next to the observer is a south pole and the other end is a north pole; if counter-clockwise, the position of the poles is reversed.

To determine the direction of the lines of force set up around a conductor: If the current in a conductor is flowing away from the observer, then the direction of the lines of force will be clockwise around the conductor.

To determine the direction of motion of a conductor carrying a current when placed in a magnetic field: Place

INDUCTION-COIL DATA SUITABLE FOR WIRELESS TELEGRAPHY AND ROENTGEN-RAY WORK

(From "Scientific American Supplement")

Length of Spark Gap Inches	Length of Core Inches	Diameter of Core Inches	Primary Wire B. & S. Gauge	Number of Layers in Primary Coil	Secondary Wire B. & S. Gauge	Secondary Wire Pounds	Condenser		Voltage of Battery
							Number of Sheet	Area of Each Sheet Square Inches	
1	3	1	23	2	36	1	25	2×1	2
2	3½	1	23	2	36	1	40	2×1½	2
3	4½	1	22	2	36	1	45	4×2	4
6	6	1	19	2	36	1	50	4×2	4
12	7	1	16	2	36	1	60	4×4	6
	8	1	16	2	36	1	100	7×5	12
	10	1	14	2	34	3	100	9×7	12
	11½	1	14	2	34	5	150	9×7	12
	14½	1	12	2	33	10	200	9×9	16
	19	1	10	3	33	12	60	12×8	10

thumb, forefinger, and middle finger of the *left hand* each at right angles to the other two; if the forefinger shows the direction of the lines of force and the middle finger shows the direction of the

FIG. 2

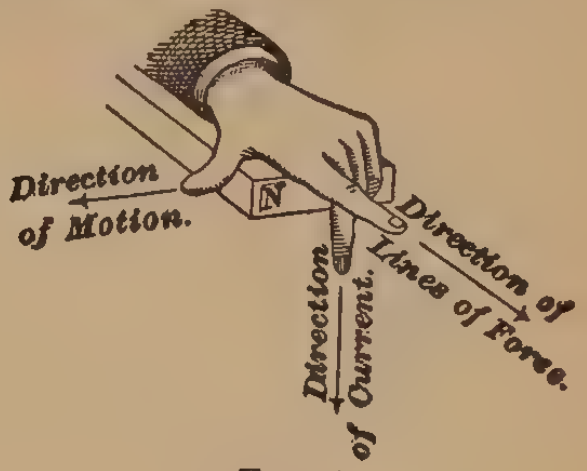


FIG. 3

current, then the thumb will show the direction of the motion given to the conductor.

To determine the direction of an induced current in a conductor that is moving in a magnetic field: Place thumb, forefinger, and middle finger of the *right hand* each at right angles to the other two; if the forefinger shows the direction of the lines of force and the thumb shows the direction of motion of the conductor, then the middle finger will show the direction of the induced current.

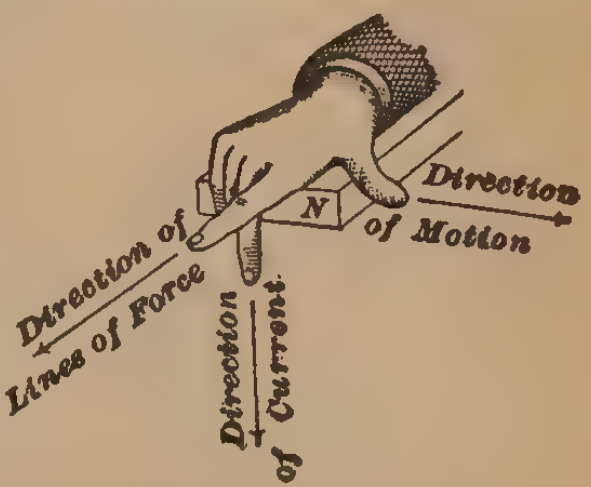


FIG. 4

A rule that is sometimes useful is the following: If the effect of the movement of a closed coil is to diminish the number of lines of force that pass through it, the current will flow in the conductor in a clockwise direction, when viewed by a person looking along the magnetic field in the direction of the lines of force; but if the effect is to increase

COTTON-COVERED ANNEALED COPPER WIRE

B. & S. Gauge	Bare		Single Cotton-Covered		
	Dia. Mils d	Area Cir. Mils d^2	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1,000}{d_x}$	Wires per Sq. In. $\left(\frac{1,000}{d_x}\right)^2$
0000	460	212,000			
000	410	168,000			
00	365	133,000			
0	325	106,000			
1	289	83,700			
2	258	66,400			
3	229	52,600			
4	204	41,700	211	4.73	22.3
5	182	33,100	189	5.29	27.9
6	162	26,300	169	5.91	34.9
7	144	20,800	151	6.62	43.8
8	128	16,500	136	7.35	54.0
9	114	13,100	121	8.26	68.2
10	102	10,400	108	9.25	85.5
11	90.7	8,230	97	10.3	106
12	80.8	6,530	87	11.4	129
13	71.9	5,180	78	12.8	163
14	64.1	4,110	70	14.2	201
15	57.1	3,260	63	15.8	249
16	50.8	2,580	56	17.8	316
17	45.3	2,050	50	20.0	400
18	40.3	1,620	45	22.2	492
19	35.9	1,290	39	25.6	655
20	32.0	1,020	36	27.7	767
21	28.5	810	32.5	30.7	942
22	25.3	642	29.0	34.4	1,180
23	22.6	510	26.6	37.5	1,400
24	20.1	404	24.1	41.4	1,710

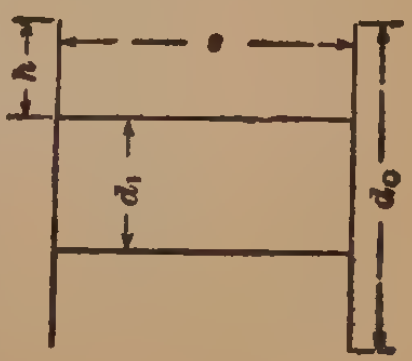
TABLE—(*Continued*)

B. & S. Gauge	Bare		Single Cotton-Covered		
	Dia Mils d	Area Cir. Mils d^2	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1,000}{d_x}$	Wires per Sq. In. $\left(\frac{1,000}{d_x}\right)^2$
25	17.9	320	21.9	45.6	2,070
26	15.9	254	19.9	50.2	2,520
27	14.2	202	18.2	54.9	3,010
28	12.6	160	16.6	60.2	3,620
29	11.3	127	15.3	65.3	4,260
30	10.0	101	14.0	71.4	5,090
31	8.93	79.7	12.9	77.5	6,000
32	7.95	63.2	11.9	84.0	7,050
33	7.08	50.1	11.1	90.0	8,100
34	6.31	39.8	10.3	97.0	9,400
35	5.62	31.5	9.6	104	10,800
36	5.00	25.0	8.5	117	13,600
37	4.45	19.8			
38	3.97	15.7			
39	3.53	12.5			
40	3.15	9.89			

the number of lines of force that pass through the coil, the current will flow in the opposite direction.

MAGNET-WINDING CALCULATIONS

Suppose a winding space, having the length s and the depth $h=\frac{d_0-d_1}{2}$, is to be filled with wire wound in layers as closely as possible. The diameter of the bare wire is d, and over the insulation d_x. The space will hold $\frac{s}{d_x}$ turns per layer and



COTTON-COVERED ANNEALED COPPER WIRE

B. & S. Gauge	Double Cotton-Covered Wire			Triple Cotton-Covered Wire		
	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1{,}000}{d_x}$	Wires per Sq. In. $\left(\frac{1{,}000}{d_x}\right)^2$	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1{,}000}{d_x}$	Wires per Sq. In. $\left(\frac{1{,}000}{d_x}\right)^2$
0000				478	2.09	4.36
000				428	2.33	5.42
00				383	2.61	6.81
0	339	2.94	8.64	343	2.91	8.46
1	303	3.30	10.8	307	3.25	10.5
2	272	3.67	13.4	276	3.62	13.1
3	242	4.13	17.0	247	4.04	16.3
4	216	4.62	21.3	220	4.54	20.6
5	194	5.15	26.5	198	5.05	25.5
6	174	5.74	32.9	178	5.61	31.4
7	156	6.41	41.0	160	6.25	39.0
8	141	7.09	50.2	145	6.89	47.4
9	126	7.93	62.8	130	7.69	59.1
10	112	8.92	79.5	116	8.02	64.3
11	101	9.90	98.0	105	9.52	90.6
12	91	10.9	118	95	10.5	110
13	82	12.1	146	86	11.6	134
14	74	13.5	182	78	12.8	163
15	67	14.9	222	71	14.0	196
16	59	16.9	285	63	15.8	249
17	53	18.8	353	57	17.5	306
18	48	20.8	432	52	19.2	368
19	43	23.2	538	47	21.2	449
20	40	25.0	625	44	22.7	515
21	36.5	27.3	745	40.5	24.6	605
22	33.0	30.3	918	37	27.0	729
23	30.6	32.6	1,060	34.6	28.9	835
24	28.1	35.5	1,260	32.1	31.1	967

TABLE—(*Continued*)

B. & S. Gauge	Double Cotton-Covered Wire			Triple Cotton-Covered Wire		
	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1,000}{d_x}$	Wires per Sq. In. $\left(\frac{1,000}{d_x}\right)^2$	Dia. Over Ins. Mils d_x	Wires per In. $\frac{1,000}{d_x}$	Wires per Sq. In. $\left(\frac{1,000}{d_x}\right)^2$
25	25.9	38.6	1,480			
26	23.9	41.8	1,740			
27	22.2	45.0	2,020			
28	20.6	48.5	2,350			
29	19.3	51.8	2,680	These small-size wires are seldom, if ever, covered with three layers of cotton.		
30	18.0	55.5	3,080			
31	16.9	59.1	3,490			
32	15.9	62.8	3,940			
33	15.1	66.2	4,380			
34	14.3	69.9	4,880			
35	13.6	73.5	5,400			
36	12.0	83.3	6,930			

$\frac{h}{d_x}$ layers, and the total turns

$$T = \frac{sh}{(d_x)^2} = \frac{s(d_0 - d_1)}{2(d_x)^2} \qquad (1)$$

The mean diameter of all the turns is

$$d_0 - h = d_0 - \frac{d_0 - d_1}{2} = \frac{d_0 + d_1}{2},$$

the length l of a mean turn is

$$\frac{\pi(d_0 + d_1)}{2},$$

and the total length of wire is

$$L = \frac{\pi T(d_0 + d_1)}{2} = \frac{\pi sh(d_0 + d_1)}{2(d_x)^2}. \qquad (2)$$

The resistance is

$$R = \frac{\pi \rho sh(d_0 + d_1)}{2(d_x)^2} \qquad (3)$$

where ρ is the resistance per unit length of wire. Since $\frac{\pi sh(d_0+d_1)}{2}=V$, the total volume of winding space, then

$$R=\frac{\rho V}{(d_x)^2} \qquad (4)$$

In general, if m is the resistance per mil-foot, a the circular mils cross-section of the wire, l the mean length in inches of one turn, and T the total number of turns, the resistance is

$$R=\frac{mlT}{12a} \qquad (5)$$

If the coil is to be used on a fixed voltage E, the current $I=\frac{E}{R}=\frac{12Ea}{mlT}$, and the ampere-turns $IT=\frac{12Ea}{ml}$ from which the circular mils

$$a=\frac{mlIT}{12E} \qquad (6)$$

For copper wire at 75° F. $m=10.5$ ohms, but if the wire is heated until the resistance is increased about 14%, the constant becomes 12 ohms, a value frequently used. If $m=12$, the formula becomes

$$a=\frac{lIT}{E} \qquad (7)$$

which gives the cross-section of wire needed for a given number of ampere-turns when the temperature of the wire is about 135° F.

By making no allowance for the thickness of insulation, except that each wire occupies a space of $d_x{}^2$ square inches, the diameter of a wire required to fill a winding space of outside diameter d_0, inside diameter d_1, and length s all in inches, and offer a given resistance of R ohms, is given approximately by the formula

$$d=.0288\sqrt[4]{\frac{s(d_0{}^2-d_1{}^2)}{R}} \qquad (8)$$

where d is the diameter of the bare wire in inches.

A more exact formula for determining the diameter is

$$d=\sqrt{i^2+\sqrt{\frac{.7854ns(d_0{}^2-d_1{}^2)}{R}}}-i \qquad (9)$$

where i is the radial thickness of the insulation, and n is the resistance of a wire 1 inch long and 1 inch in diameter.

The bare diameter d of a wire for a coil that will produce IT ampere-turns with a given voltage E may be determined from the formula

$$d = \sqrt{\frac{.000001374(d_0 + d_1)IT}{E}} \qquad (10)$$

The length of insulated wire on a spool or bobbin is given by the formula

$$L = \frac{.7854s(d_0^2 - d_1^2)}{(2i + d)^2} \qquad (11)$$

When the volume V of the winding space in cubic inches and the ohms per cubic inch o of the sized wire used is known, the resistance of a coil can be determined from the formula

$$R = Vo = .7854so(d_0^2 - d_1^2) \qquad (12)$$

The heating effect of the energy lost in a magnet coil depends on the shape of the coil and on the conditions of ventilation. If d_0 is the outside diameter of a coil and s is its length, both in inches, and W is the total watts lost in the coil, the watts per square inch of cylindrical surface is

$$w = \frac{W}{\pi d_0 s}$$

The safe value for w varies generally from .25 to 1.5, a fair value, if the ventilating conditions are good, being .75 to 1 for coils at 75° F. above the temperature of the surrounding air. Higher values of w can be used only for exceptionally good ventilating conditions or for intermittent-service conditions.

Since $W = I^2R = \frac{E^2}{R}$, $R = \frac{E^2}{W} = \frac{E^2}{\pi d_0 s w}$, which gives the resistance of a coil when dissipating w watts per square inch.

The following formula gives the diameter d of a wire that will produce the greatest number of ampere-turns with a rise in temperature of $t°$ F..

$$d = \sqrt{\sqrt{.000002159 \times (1 + .00223t°) \times d_0 \times s^2 \times (d_0^2 - d_1^2) W_s} + i^2} - i$$

in which i is the radial thickness of the insulation on the wire, and W_s is the watts radiated per square inch of cylindrical surface of the coil.

The greatest number of ampere-turns IT that can be obtained in a coil of given size for a given voltage E, a given rise in temperature t°F., and W_s watts radiated per square

inch of cylindrical surface, can be calculated from the formula

$$IT = \frac{E\left[\sqrt{\sqrt{\frac{.000002159\times(1+.00223\,t^{\circ})\times d_0\times s^2\times(d_0^2-d_1^2)\times Ws}{E^2}}+i^2}-i\right]^2}{.000001374\times(d_0+d_1)}$$

DRY-CORE PAPER-INSULATED TELEPHONE CABLES

No. of Pairs	No. 19 B. & S. Wire			No. 20 B. & S. Wire	No. 22 B. & S. Wire		
	Diameter of Cable Inches	Splicing Sleeve		Diameter of Cable	Diameter of Cable Inches	Splicing Sleeve	
		Diameter Inches	Length Inches			Diameter Inches	Length Inches
15		2	20			1½	18
20	1.134	2	20	1.032	.860	1½	18
25	1.169	2	25	1.100	.928	2	20
50	1.534	2	28	1.427	1.251	2	20
75	1.822	2¼	28	1.648	1.461	2¼	22
100	2.063	2½	28	1.907	1.632	2½	24
125	2.268	3	28	2.102	1.805	2¾	28
150	2.457	3	30	2.269	1.943	3	28
175	2.630	3¼	30	2.423	2.080	3	28
200	2.784	3½	32	2.578	2.200	3	28
300		4	36		2.630	3½	28
400		4	40			4	28

Each conductor has a capacity of .08 microfarad per mile. The 20-pair No. 20 B. & S. conductor cable and the 25-pair No. 22 B. & S. conductor cable have lead sheaths $\frac{7}{64}$ in. thick, the 20-pair No. 22 B. & S. conductor cable has a lead sheath $\frac{3}{32}$ in. thick; all others have lead sheaths $\frac{1}{8}$ in. thick. For Y and loop splices, use a sleeve one size larger than given for straight splices in this table.

Concrete.—For manholes and around conduits good concrete may be made of 1 part of Portland cement or 2 parts of Rosendale or native cement, 3 parts of sand, and 5 or 6 parts of broken stone, or good cinders or furnace slag, that will pass through a ring 1½ inches in diameter, but not through a ring ¼ inch in diameter. For good results, concrete should be mixed as follows First, mix the sand and cement, turning them together at least three times dry, then add the stone, which should previously have been thoroughly wetted, and turn the mixture at least once over, finally add enough water to make the concrete tamp nicely, but not so moist as to have water run from it, and turn over at least three times. The water should not be supplied from a hose giving a strong stream that will cause the finely divided cement to be washed away; use buckets or a weak stream of water.

Poles.—Telephone and telegraph poles 25-ft. long should be set in 5-ft. holes; 30-ft. poles in 5½-ft. holes; 35- and 40-ft. poles in 6-ft. holes; 45-ft. poles in 6½-ft. holes; 50-ft. poles in 7-ft. holes; 55-ft. poles in 7½-ft. holes; 60-ft. poles in 8-ft. holes; 65-ft. poles in 8½-ft. holes; 70-ft. poles in 9-ft. holes; 75-ft. poles in 9½-ft. holes; 80-ft. poles in 10-ft. holes; 85-ft. poles in 10½-ft. holes, 90-ft. poles in 11-ft. holes. Poles on corners should be set about ½ ft. deeper.

Cross-arms should be placed at such a height on poles that the lowest wire will be, in hot weather, at least 27 ft. and preferably 30 ft. above railroad rails over which the wire crosses. Double cross-arms should be used on each side of a railroad track. Poles along a railroad should be at least 7 feet from the nearest rail with lowest cross-arm at least 22 ft. above rail. Lowest wire crossing a public road should be at least 19 ft. above crown of road. Standard telephone and telegraph cross-arms are 3¼ in. × 4¼ in., and so-called telephone cross-arms are 2¾ in. × 3¾ in.

For telephone drop lines, extending from line or cable to the house, many companies use a rubber-covered and braided copper, and occasionally iron, wire of No. 14 or 16 B. & S. gauge. Usually this wire comes twisted in pairs, but occasionally two single wires are used.

SILK- AND COTTON-COVERED ANNEALED COPPER WIRE

(S. G. McMeen in "Telephony")

B. & S. Gauge	Diameter in Mils					Ohms per Cubic Inch		
	Bare	Single Cotton	Double Cotton	Single Silk	Double Silk	Single Cotton	Double Cotton	Single Silk
20	31.961	37.861	42.161	34.261	36.161	.646	.533	.801
21	28.462	34.362	38.662	30.762	32.662	.981	.795	1.261
22	25.347	31.247	35.547	27.647	29.547	1.502	1.188	1.956
23	22.571	28.471	32.771	24.871	26.771	2.359	1.772	3.049
24	20.100	26.000	30.300	22.401	24.300	3.582	2.595	4.739
25	17.900	23.800	28.100	20.200	22.100	5.831	3.802	7.489
26	15.940	21.840	26.140	18.240	20.140	6.941	5.552	9.031
27	14.195	20.095	24.395	16.495	18.395	10.814	8.078	13.92
28	12.641	18.541	22.841	14.941	16.841	17.617	11.54	26.86
29	11.257	17.157	21.457	13.557	15.457	25.500	16.47	41.29
30	10.025	15.925	20.225	12.325	14.225	34.800	23.43	62.98
31	8.928	14.828	19.128	11.228	13.128	48.5	32.83	95.70
32	7.950	13.850	18.150	10.250	12.150	73.8	46.19	144.70
33	7.080	12.980	17.280	9.380	11.280	104.5	64.30	217.8
34	6.304	12.204	16.504	8.504	10.504	151.4	70.38	342.1
35	5.614	11.514	15.841	7.914	9.814	202.0	125.9	489.0
36	5.000	10.900	15.200	7.300	9.200	298.8	166.3	721.1
37	4.453	10.353	14.653	6.753	8.653	418	225.6	1062
38	3.965	9.865	14.165	6.265	8.165	567	305.5	1557
39	3.531	9.431	13.731	5.831	7.731	811	409.8	2266
40	3.144	9.044	13.344	5.344	7.344	1113	545.5	3400

SILK- AND COTTON-COVERED ANNEALED COPPER WIRE

B. & S. Gauge	Turns per Linear Inch				Turns per Square Inch			
	Single Cotton	Double Cotton	Single Silk	Double Silk	Single Cotton	Double Cotton	Single Silk	Double Silk
20	25.7	22.5	27.70	26.22	660.5	506.3	767.3	687.5
21	28.3	24.5	30.97	29.07	800.9	600.2	959.1	845.0
22	31.0	26.7	34.39	32.11	961.0	712.9	1,182.7	1,031.0
23	34.4	28.97	38.19	35.53	1,183.0	839.2	1,458.5	1,262.4
24	36.9	31.35	42.37	39.14	1,321.6	982.8	1,795.2	1,532.0
25	38.0	33.92	47.02	42.94	1,444.0	1150.8	2,210.9	1,843.8
26	42.0	36.29	52.06	46.81	1,764.0	1317.0	2,710.3	2,191.2
27	48.0	38.95	57.67	51.59	2,304.0	1517.2	3,326.0	2,661.6
28	53.0	41.61	63.36	56.43	2,809.0	1731.0	4,014.5	3,184.5
29	56.5	44.27	70.11	61.56	3,192.3	1959.9	4,915.5	3,789.8
30	59.66	46.93	77.14	66.79	3,559.2	2202.5	5,950.2	4,461.0
31	64.12	49.78	84.64	72.39	4,112.2	2478.0	7,164.0	5,240.0
32	68.60	52.34	92.72	78.19	4,692.5	2739.5	8,597.5	6,114.0
33	73.05	55.10	101.65	84.17	5,333.5	3036.1	10,332	7,085.0
34	77.90	57.57	112.11	90.44	6,068.5	3314.2	12,570	8,179.5
35	82.60	60.04	119.7	96.90	6,773.3	3605.0	14,328	9,389.5
36	87.10	62.51	130.15	103.55	7,586.5	3907.5	16,940	10,722
37	91.87	64.70	140.60	110.20	8,440.0	4186.1	19,770	12,145
38	95.0	66.80	151.05	116.85	9,025.0	4462.2	22,820	13,655
39	100.7	68.80	163.04	122.55	10,140.5	4733.6	26,700	15,018
40	106.0	71.20	177.65	129.20	11,236.0	5069.8	31,559	16,692

DIAMETERS OF WIRES OF VARIOUS MATERIALS THAT WILL BE FUSED BY A CURRENT OF GIVEN STRENGTH

(W. H. Preece, F. R. S.)

Current Amperes	Diameters in Inches								
	Copper	Aluminum	Platinum	German Silver	Platinoid	Iron	Tin	Tin-Lead Alloy	Lead
1	.0021	.0026	.0033	.0033	.0035	.0047	.0072	.0083	.0081
2	.0034	.0041	.0053	.0053	.0056	.0074	.0113	.0132	.0128
3	.0044	.0054	.007	.0069	.0074	.0097	.0149	.0173	.0168
4	.0053	.0065	.0084	.0084	.0089	.0117	.0181	.021	.0203
5	.0062	.0076	.0098	.0097	.0104	.0136	.021	.0243	.0236
10	.0098	.012	.0155	.0154	.0164	.0216	.0334	.0386	.0375
15	.0129	.0158	.0203	.0202	.0215	.0283	.0437	.0506	.0491
20	.0156	.0191	.0246	.0245	.0261	.0343	.0529	.0613	.0595
25	.0181	.0222	.0286	.0284	.0303	.0398	.0614	.0711	.069
30	.0205	.025	.0323	.032	.0342	.045	.0694	.0803	.0779

35	.0227	.0277	.0358	.0356	.0379	.0498	.0769	.089	.0864
40	.0248	.0303	.0391	.0388	.0414	.0545	.084	.0973	.0944
45	.0268	.0328	.0423	.042	.0448	.0589	.0909	.1052	.1021
50	.0288	.0352	.0454	.045	.048	.0632	.0975	.1129	.1095
60	.0325	.0397	.0513	.0509	.0542	.0714	1101	.1275	.1237
70	.036	.044	.0568	.0564	.0601	.0791	.122	.1413	.1371
80	.0394	.0481	.0621	.0616	.0657	.0864	.1334	.1544	.1499
90	.0426	.052	.0672	.0667	.0711	.0935	.1443	.1671	.1621
100	.0457	.0558	.072	.0715	.0762	.1003	.1548	.1792	.1739
120	.0516	.063	.0814	.0808	.0861	.1133	.1748	.2024	.1964
140	.0572	.0698	.0902	.0895	.0954	.1255	.1937	.2243	.2176
160	.0625	.0763	.0986	.0978	.1043	.1372	.2118	.2452	.2379
180	.0676	.0826	.1066	.1058	.1128	.1484	.2291	.2652	.2573
200	.0725	.0886	.1144	.1135	.121	.1592	.2457	.2845	.276
225	.0784	.0958	.1237	.1228	.1309	.1722	.2658	.3077	.2986
250	.0841	.1028	.1327	.1317	.1404	.1848	.2851	.3301	.3203
275	.0897	.1095	.1414	.1404	.1497	.1969	.3038	.3518	.3417
300	.095	.1161	.1498	.1487	.1586	.2086	.322	.3728	.3617

Underwriters' Rules.—In order to have buildings insurable, all interior wiring must be installed according to the *National Electrical Code*, a set of rules and requirements adopted by the National Board of Fire Underwriters. Copies of this code and of the *list of approved fittings* may be obtained from any local Inspection Bureau or from the National Board of Fire Underwriters, New York or Chicago. The following are some of the requirements.

ELECTRIC TRANSMISSION

ELECTRIC CIRCUITS AND SYSTEMS OF DISTRIBUTION

An *electric circuit* is the complete conducting path of an electric current. The circuit is *closed* when the current can flow, *open* when it has one or more breaks that prevent the current from flowing, and *grounded* when some part is in contact with the earth or with some conductor leading to earth. A source of E. M. F. is *short-circuited* when its terminals are connected by a conducting path of very low resistance.

FIG. 1. SERIES SYSTEM

Electric energy may be distributed in any of several different ways: (1) By connecting all the receiving devices of the circuit in series, as shown in Fig. 1, and keeping the current through the circuit constant; for example, in street lighting, by means of a series of arc or incandescent lamps. (2) By connecting the receiving devices in parallel, as in Fig. 2, and subjecting all to a constant E. M. F., as in most systems of

incandescent lighting. (3) By connecting two or more devices in series, and a number of these series in parallel across constant-potential circuits, as shown in Fig. 3; for example, some special systems of incandescent lighting. For any of these three methods, either direct or alternating current may be used.

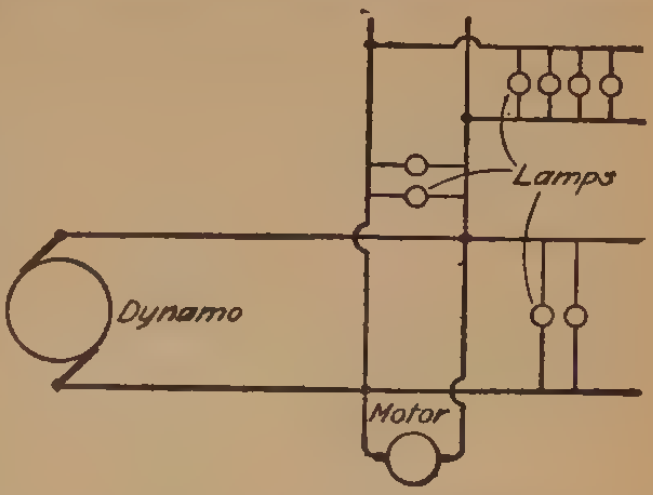


FIG. 2. PARALLEL SYSTEM

ELECTRIC CONDUCTORS

Electric conductors are usually made of copper, though for some long-distance aerial transmission lines aluminum is used. Solid cylindrical wire, Fig. 4, is generally used, unless the diameter required is greater than $\frac{3}{8}$ to $\frac{1}{2}$ in. or unless great flexibility is desired, in which cases cable, Figs. 5 and 6, consisting of a number of smaller wires twisted together is better. For aerial work in sparsely settled territory, bare wire is considered good enough; but in most other cases, the wire or cable is insulated by a covering of two or three layers of cotton soaked in a weather-proof compound. For underground work, the conductor is first covered with layers of rubber or paper soaked in compound, and then all is covered with a lead

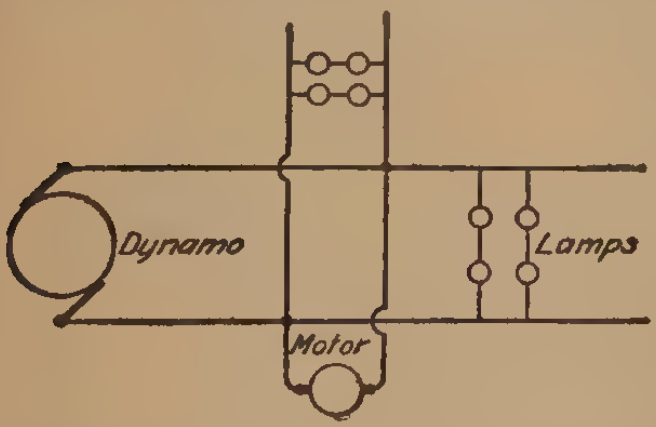


FIG. 3. PARALLEL-SERIES SYSTEM

FIG. 4. INSULATED WIRE

sheathing, as shown in Fig. 6. Two or more conductors may be individually insulated and then all wrapped and insulated as one cable, as in Fig. 7; the several conductors may lie side by side in a cable or may be arranged concentrically. For telephone and telegraph work, a large number of insulated conductors are sometimes included in one cable.

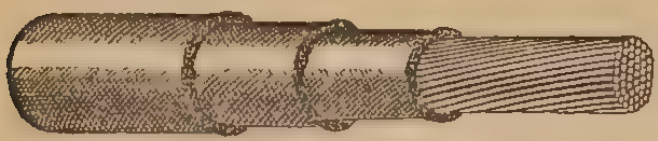


FIG. 5. INSULATED CABLE

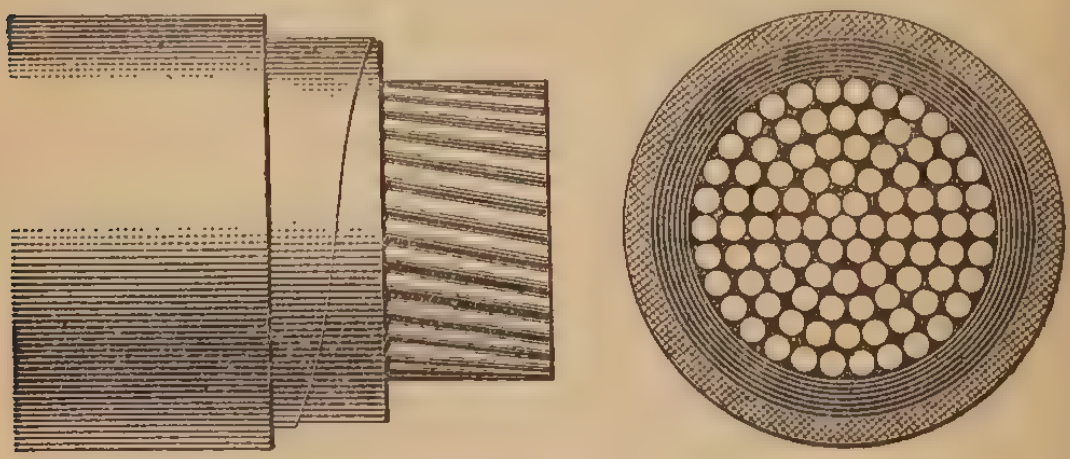


FIG. 6. LEAD-COVERED CABLE

CONDITIONS GOVERNING SIZE OF CONDUCTORS

In order to send a current I through a conductor of resist-

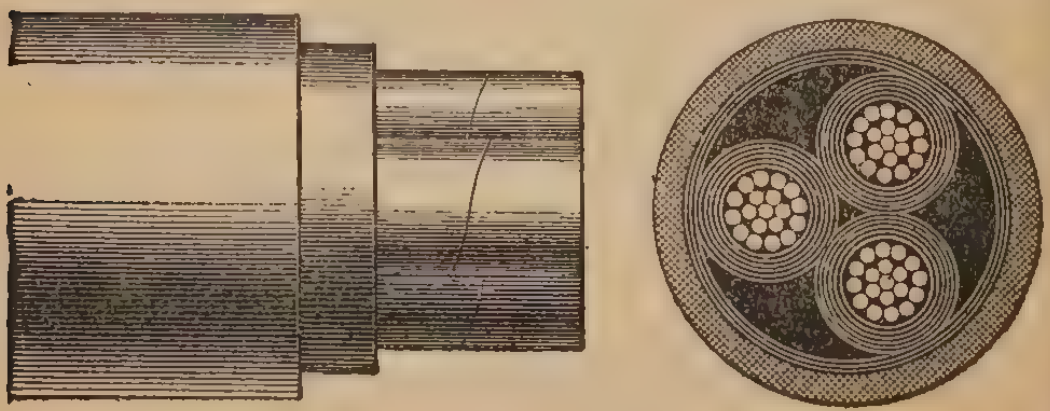


FIG. 7. THREE-CONDUCTOR CABLE

ance R, there is required a pressure $e = IR$; that is, e is the *drop of pressure* in the conductor. Since the product of

current and the pressure producing it is the work done, the product Ie is the work done in sending the current through the conductor, and this work heats the conductor. The resistance of a cylindrical conductor is expressed by the formula

$$R = \frac{ml}{d^2},$$

in which m is a constant, l the length of the conductor in feet, and d its diameter in mils (1 mil = .001 in.). For the grade of copper used for electric conductors, $m = 10.65$ at 25° C. and 12.3 at 65° C.; for ordinary wiring calculations, m may be taken at 10.8. The value of m for aluminum wire may be taken at 17.2.

For a given length of conductor, the resistances can be made small by using a conductor of large diameter, or cross-section; but the cost of the installation will thereby be increased.

Economical Conditions.—In laying out a transmission system, the following points should be considered:

1. The conductors must be so proportioned that the energy transmitted through them will not cause an undue rise of temperature.

2. The conductors must have such mechanical properties as to enable them to be successfully erected, and so durable as to require a minimum of annual maintenance.

3. The conductors may be so chosen (*a*) that the first cost of line construction shall be a minimum; (*b*) that the station construction shall be a minimum; (*c*) that the cost of the plant shall be reduced and the cost of operation and maintenance be a minimum; (*d*) that the total first cost of installation shall be a minimum; (*e*) that the conditions of good service shall be a maximum; (*f*) that the total first cost of the plant shall be a minimum, consistent with maximum income.

The success of any system requires that conditions Nos. 1 and 2 be fulfilled. It is not possible to fulfil all of the conditions in No. 3; the success of a particular installation depends on the securing of a proper balance of these conditions and the selection of the proper one to be governing

or most prominent. The economical conditions may be considered in detail as follows:

1. Except in interior wiring, the question of heating of conductors used for electric transmission is seldom of importance, since the proper proportioning of the conductors to meet the other conditions will make them so large that they will not overheat. A table of safe carrying capacities of various sizes of wire will be found under Interior Wiring.

2. In every installation, thought should be given to the maximum stresses to which any of the parts are ever likely, under ordinary conditions, to be subjected, that is, ordinary windstorms, snow and sleet, etc. bring to bear on aerial conductors and their supports stresses much greater than those to which they are subjected while being installed, and the various parts must be strong enough to withstand the more severe conditions. Ordinarily, conductors selected with a view of obtaining economical transmission will be strong enough mechanically; but this is not always the case, and special investigation should be made in each case of doubt.

3. (*a*) If a transmission line is installed for temporary purposes only, as for lighting or for running motors for construction work, it should be made as cheaply as possible, consistent with safety, regardless of the effect on the cost of the generating station; for the materials used in the line construction will be of little value second hand, while the engines and dynamos used in the station will not be much injured by the temporary use.

3. (*b*) In some cases it may be desirable to make the station cost a minimum. The line losses must then be a minimum, for the station must not be compelled to generate more energy than is absolutely necessary. This will require large line conductors with correspondingly high cost. For example, in city territory with underground lines, it should very seldom be necessary to take up a line for repair or renewal; hence, the transmission line should be installed large enough to care for future growth, while the station cost may be comparatively low with provision for installing increased capacity when needed.

3. (*c*) If by using small conductors the *cost of the transmission system* is made low, the transmission losses will be correspondingly high, thus increasing the *cost of the station* and the *cost of operation*. On the other hand, the cost of the station and of operation may be made low by using large conductors, so as to occasion small losses. In every plant, such a relation of these three costs to one another should obtain so that the sum of the three shall be a minimum. Sir William Thomson (Lord Kelvin) in 1881 deduced a law, an exact statement of which is made by Gisbert Kapp, as follows:

The most economical area of conductor is that for which the annual cost of energy wasted is equal to the interest on that portion of the capital outlay which can be considered to be proportional to the weight of metal used.

The specific weight of hard-drawn copper wire, such as used for electrical conductors, is .32 lb. per cu. in. The weight of a wire d mils in diameter and L thousand ft. long is, therefore,

$$\frac{d^2 \times .7854}{10^6} \times 1{,}000L \times 12 \times .32 = .003Ld^2$$

If K is the cost per pound of copper wire in place on the line, and with interest at 1%, the annual interest on the cost of the conductors is

$$A = .01K \times .003Ld^2$$

Since the resistance of the line is $\frac{10.8 \times 1{,}000L}{d^2}$, the kilowatts lost in transmitting a current of I amperes is $\frac{10.8I^2L}{d^2}$, and if K' is the cost in dollars per kilowatt-year to generate the power, then the annual cost of the lost power is

$$B = \frac{10.8K'I^2L}{d^2}$$

According to Kelvin's law, for the most economical area of conductor, $A = B$, or

$$.01K \times .003Ld^2 = \frac{10.8K'I^2L}{d^2}$$

or,

$$d^3 = 600I\sqrt{\frac{K'}{K}} \qquad (1)$$

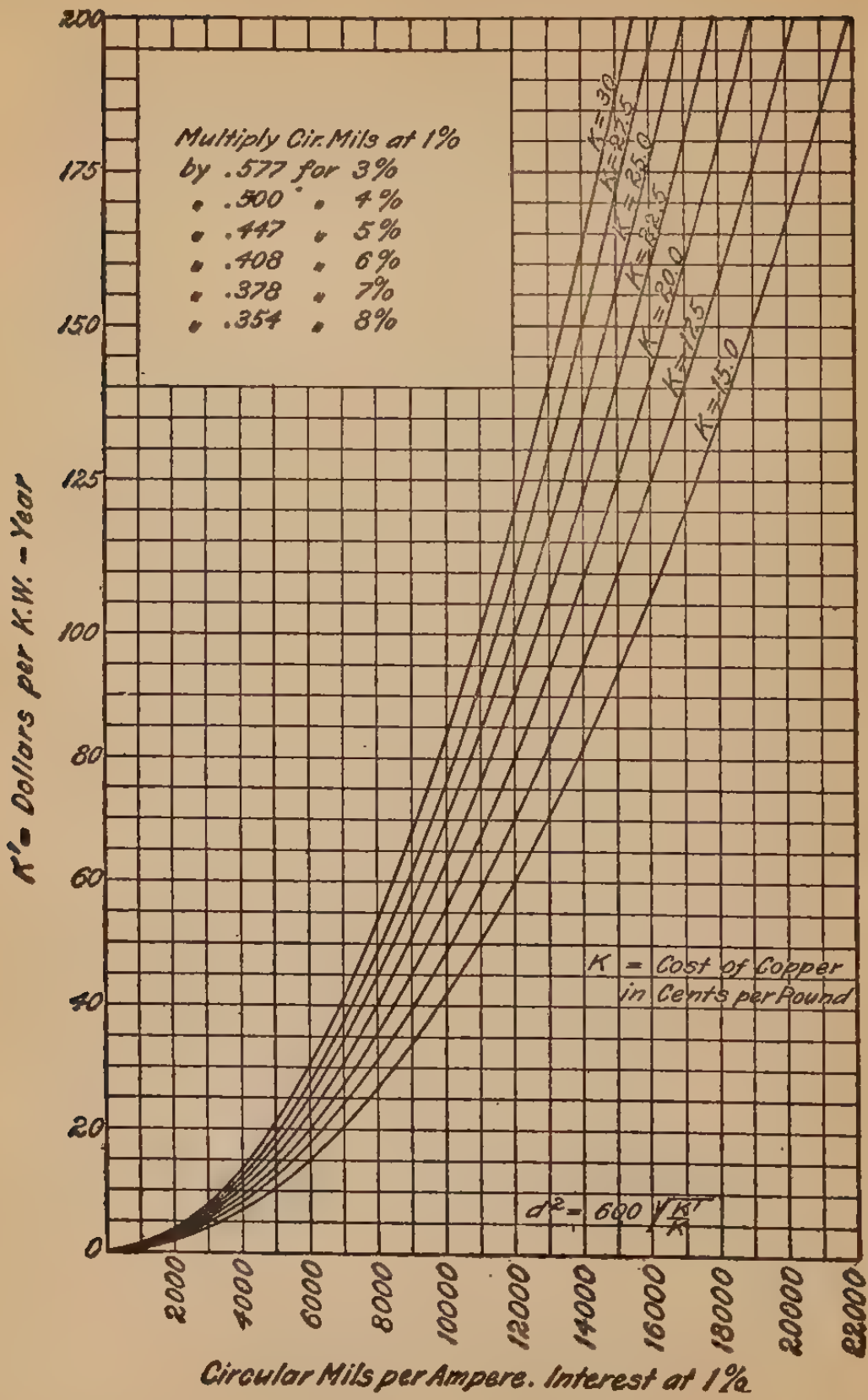


FIG. 8. SIZES OF COPPER CONDUCTORS

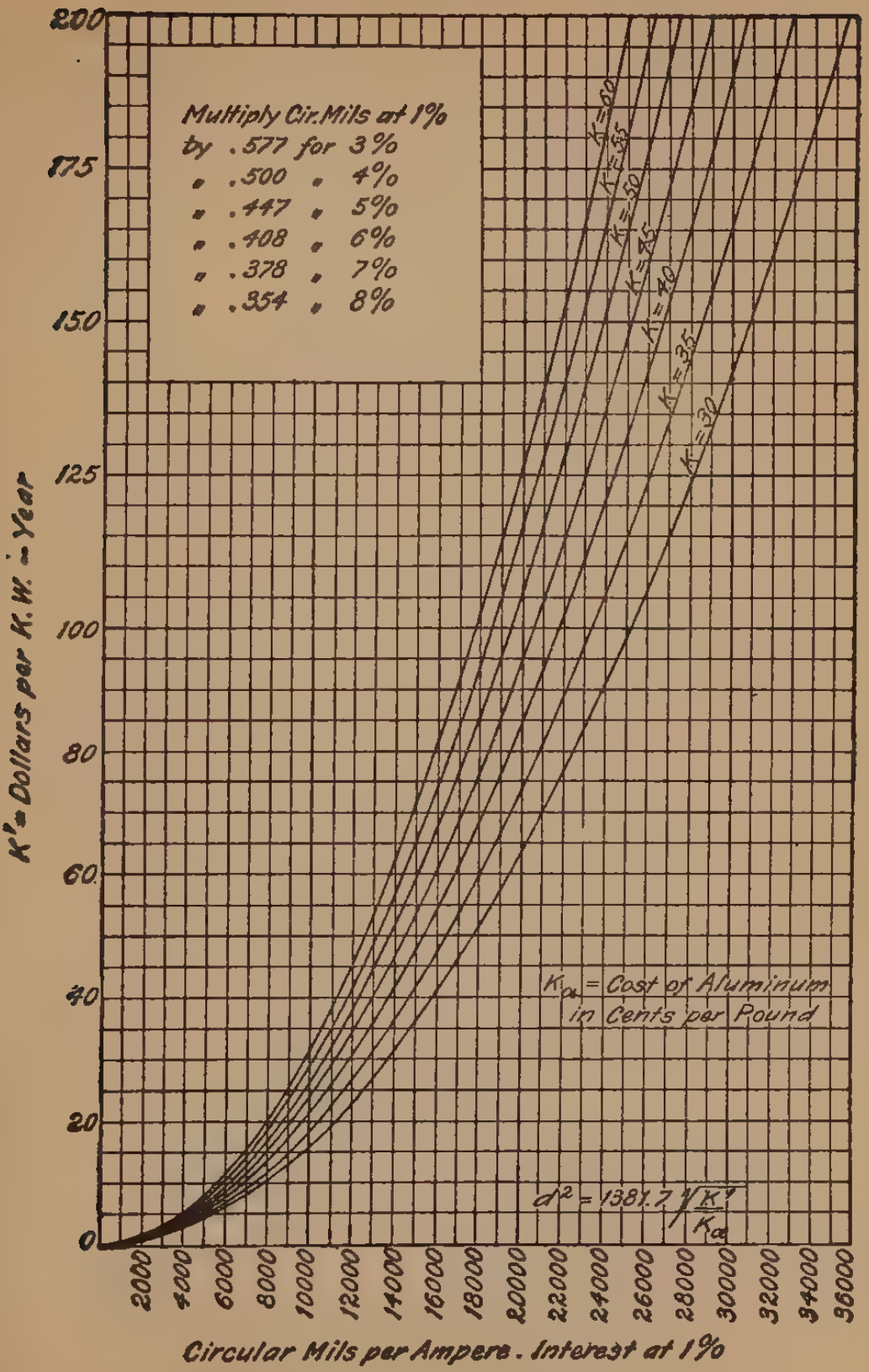


FIG. 9. SIZES OF ALUMINUM CONDUCTORS

This formula gives the most economical sectional area in circular mils d^2 of copper conductor for transmitting any current I at any voltage for any distance, with interest at 1%, for any rate of interest i, the formula becomes

$$d^2 = 60I\sqrt{\frac{K'}{iK}}$$

Since aluminum wire weighs .096 lb. per cu. in., the weight of a wire d mils in diameter and L thousand ft. long is $.0009Ld^2$. If K_a is the cost per lb. of aluminum wire in place on the line and interest is 1%, the annual interest on the cost of aluminum conductors is

$$A = .01K_a \times .0009Ld^2$$

The power lost in transmission is $\frac{17.2I^2L}{d^2}$, and the annual cost of the transmission losses is

$$B = \frac{17.2K'I^2L}{d^2}$$

With interest at 1%, the most economical area of aluminum conductor for any current, voltage, and distance occurs when $A = B$; that is,

$$.01K_a \times .0009Ld^2 = \frac{17.2K'I^2L}{d^2}$$

or,
$$d^2 = 1{,}382I\sqrt{\frac{K'}{K_a}} \qquad (2)$$

or, for any rate of interest i,

$$d^2 = 138.2I\sqrt{\frac{K'}{iK_a}}$$

Formulas 1 or 2 may be made to express circular mils per ampere by dividing their second members by I in each case. The curves, Figs. 8 and 9, show the circular mils per ampere required for the most economical conditions at different costs per kilowatt-year for generating electrical energy and at several different costs per pound of copper and aluminum, respectively, in place on the line, with interest on the cost of the conductors at 1%. For example, if it costs $60 to generate 1 kilowatt-year, the most economical sectional area of copper conductor at 20 ct. per lb. is about 10 400 circular mils per ampere, and of aluminum conductor at 45 ct. per lb. is about 15,950 circular mils per ampere.

The higher the rate of interest, the less should be the cost of the conductors, the sizes varying as $\sqrt{\frac{.01}{i}}$, where i is expressed decimally. For example, at $40 per kilowatt-year and with copper at 20 ct. per lb., 8,480 circular mils per ampere should be used if the rate of interest is 1%; if the rate is 5%, the circular mils per ampere should be $8{,}480 \times \sqrt{\frac{.01}{.05}} = 8{,}450 \times .447 = 3{,}780$. The curves can therefore be used for any rate of interest by multiplying the value found for 1% by a factor corresponding to the required rate.

MEAN ANNUAL CURRENT

$\frac{1}{4}I$	$\frac{1}{2}I$	$\frac{3}{4}I$	I	Ratio
0	0	0	1	1.000
0	0	$\frac{1}{4}$	$\frac{3}{4}$	.944
0	$\frac{1}{4}$	0	$\frac{3}{4}$	.901
0	0	$\frac{1}{2}$	$\frac{1}{2}$	.884
$\frac{1}{4}$	0	0	$\frac{3}{4}$	.875
0	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{2}$	.838
0	0	$\frac{3}{4}$	$\frac{1}{4}$	.820
$\frac{1}{4}$	0	$\frac{1}{4}$	$\frac{1}{2}$	.810
0	$\frac{1}{2}$	0	$\frac{1}{2}$	.790
0	$\frac{1}{4}$	$\frac{1}{2}$	$\frac{1}{4}$	.771
$\frac{1}{4}$	$\frac{1}{4}$	0	$\frac{1}{2}$	.760
$\frac{1}{4}$	0	$\frac{1}{2}$	$\frac{1}{4}$	.744
$\frac{1}{2}$	0	0	$\frac{1}{2}$	.729
0	$\frac{1}{2}$	$\frac{1}{4}$	$\frac{1}{4}$	.718
$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	$\frac{1}{4}$	.685
0	$\frac{3}{4}$	0	$\frac{1}{4}$	.661
$\frac{1}{2}$	0	$\frac{1}{4}$	$\frac{1}{4}$	.650
$\frac{1}{4}$	$\frac{1}{2}$	0	$\frac{1}{4}$	.611
$\frac{1}{2}$	$\frac{1}{4}$	0	$\frac{1}{4}$	.586
$\frac{3}{4}$	0	0	$\frac{1}{4}$	.545

Before determining the size of conductors by this method, it is necessary to know the cost of generating energy per kilowatt per year. This cost should include labor, material, interest and depreciation, insurance and taxes, etc. on the station. This information, together with the cost per pound of the line copper in place—that is, cost of copper per pound

delivered plus cost per pound to put in place and insulate—is sufficient to enable the most economical cross-section in circular mils per ampere to be selected by means of the curves. The number found by the curves multiplied by the number of amperes to be transmitted gives the total cross-section required. It is possible to use copper 20% smaller than given by the curves without increasing the transmission losses more than 1 or 2%.

If less than full current I is to be carried a portion of the time, the *mean annual current*, determined by multiplying the full-load current by the ratios in the accompanying table, should be used in making calculations:

For example, a line to carry 100 amperes (I) three-fourths of the time and 75 amperes ($\frac{3}{4}I$) one-fourth of the time should be calculated for $100 \times .944 = 94.4$ amperes. A line carrying $\frac{1}{2}I$ one-fourth of the time, $\frac{3}{4}I$ one-half of the time, and I (full load) one-fourth of the time should be calculated for .771 I amperes, etc.

3. (*d*) If the plant is installed for a temporary purpose only and the whole installation is chargeable to the temporary service, the cost of both station and line construction should be made low, regardless of increased operating and maintenance expenses.

3. (*e*) For supplying current to constant-potential devices in multiple, the size of the conductors must be calculated so that the pressure drop in the lines to any device shall not be excessive. The drop e is

$$IR = \frac{mlI}{d^2}$$

Or, for copper,

$$e = \frac{10.8lI}{d^2} \text{ and } d^2 = \frac{10.8lI}{e},$$

in which d is the diameter of the wire, in mils, and d^2 the circular mils area, l is the length in feet, and I the current, in amperes. If D is the distance in feet (one way) for a two-wire circuit, the formula may be written

$$d^2 = \frac{21.6DI}{e}$$

Since $D = l \div 2$, the constant 10.8 is multiplied by 2.

For example, suppose it is desired to transmit 200 amperes 5,000 ft. with a drop of 50 volts; then,

$$d^2 = \frac{21.6 \times 5{,}000 \times 200}{50} = 432{,}000 \text{ cir. mils}$$

Reference to the table of B. & S. gauge copper wire shows that two No. 0000 wires would have about the correct cross-section. The size of wire required in a given case is sometimes more quickly determined by reference to wiring tables, such as found under Interior Wiring.

3. (*f*) If power is cheap and the cost of materials for the transmission line is high, the line installation is usually made as cheaply as is consistent with the service required. However, sufficient allowance should be made for growth, otherwise, taking on additional customers may cause excessive line losses, thus calling for expensive additions to the station.

THREE-WIRE SYSTEMS

In the *Edison three-wire system*, Fig. 10, two dynamos alike in voltage and capacity are connected in series between the outside wires, and the neutral wire is connected with a point in the circuit between the two machines. Being in series, the E. M. F.'s of the two machines are added, making the voltage between the outside wires double that between either outside wire and the neutral wire. The lamps are connected between either outside wire and the neutral wire, and if an equal number is connected on each side—that is, if the system is *balanced*—no current flows in the neutral wire. In any case, the current in the neutral wire is the difference between the currents in the two sides, and this difference should be made as small as possible by connecting an equal number of lamps on each side. The direction of the current in the neutral wire depends on which side has the greater number of lamps burning. Motors for

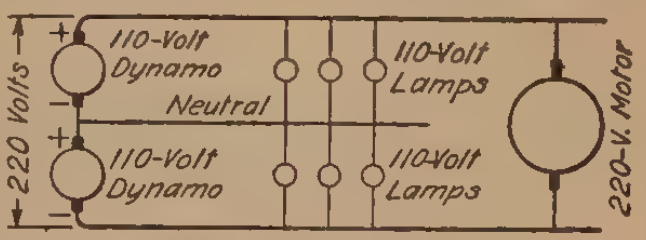


FIG. 10. THREE-WIRE SYSTEM

such a system are usually wound for the full voltage between the outside wires.

Size of Wires.—The outside wires are calculated as for a two-wire system having the higher voltage. The more perfect the balancing, the smaller may be the neutral wire, but as some unbalancing is always likely to occur, owing to switching on or off lamps from either side, it is customary to make the neutral wire at least one-half as large as either outside wire, and in many cases all three wires are the same size.

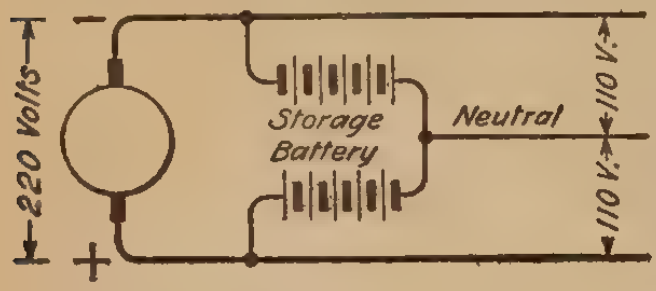


FIG. 11.

Special Three-Wire Systems.—A three-wire system may be supplied from a single dynamo or from a circuit of double the desired lamp voltage, in any of several different ways. The neutral wire may be connected to the middle point of a *storage battery*, as in Fig. 11. Each half of the battery has cells enough to maintain the voltage desired at the lamps;

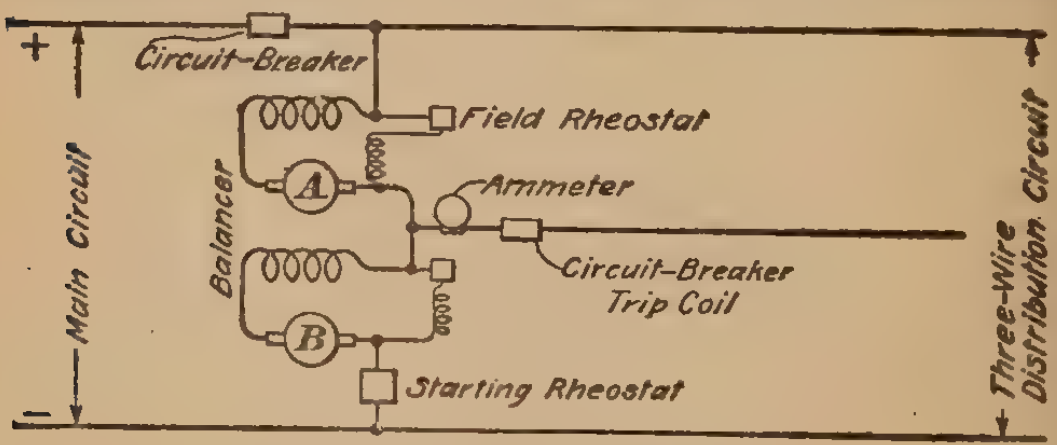


FIG. 12. BALANCING SET

each half will then discharge when the number of lamps burning on its side greatly exceeds that on the other side, and will be charged under the reverse condition. If used continuously in this way, the cells should be inspected occasionally to see that they do not become unevenly discharged

Balancing Set.—Two small dynamos, *A*, *B*, **Fig. 12, with** shafts continuous or rigidly coupled together, called a *balancing set*, or *balancer*, are often used to change from a two-wire to a three-wire system. Eacn armature is wound for the desired lamp voltage—one-half the voltage of the circuit across which the set is to be used—and the two are connected in series across the outside wires. The neutral wire is connected between the two armatures. Each armature acts at a generator when the lamps on its side require an excess of current, the other armature at the same time acting as a motor to drive the generator.

If the system is perfectly balanced, no current flows in the neutral wire and the set runs idle at a speed sufficient for each armature to generate a counter E. M. F. very nearly equal to one-half the E. M. F. across the outside wires. If the current required on one side *A* exceeds that on the other *B*, the voltage on side *A*, without the effect of the balancer, would drop, while that on side *B* would rise, their sum remaining at all times equal to the voltage across the outside wires. If the outside voltage is 220, as soon as the E. M. F. on side *A* drops below, say, 109 volts, armature *A* acts as a generator to maintain the voltage, while the rise of pressure on side *B* makes armature *B* continue to act as a motor, driving *A* at nearly a constant speed. If each field of the balancer set has a few series turns so connected that when either machine is running as a generator its field is cumulatively compound-wound, and when running as a motor is differentially compound-wound, the voltage of the generator will be slightly increased, owing both to its increased field strength and to the increased speed of the set due to weakening the field of the motor. In this way, almost perfect balance of E. M. F. on the two sides can be maintained at any degree of unbalancing of the load. A trip coil in the neutral wire opens the main circuit-breaker if the current in the neutral wire becomes excessive.

Storage batteries and balancer sets can be placed near the lamps to be supplied. Only two wires, therefore, are necessary to lead from the station to a distant building or center from which a three-wire distribution may be fed.

Dobrowolsky Three-Wire Dynamo.—By mounting a pair of collector rings on the shaft of an ordinary direct-current dynamo, and connecting each ring to equipotential points (two for each pair of poles) on the commutator, or armature winding, an alternating E. M. F. will be impressed on the collector rings while the machine is operating; and if a choke coil is connected between the two rings, and the neutral

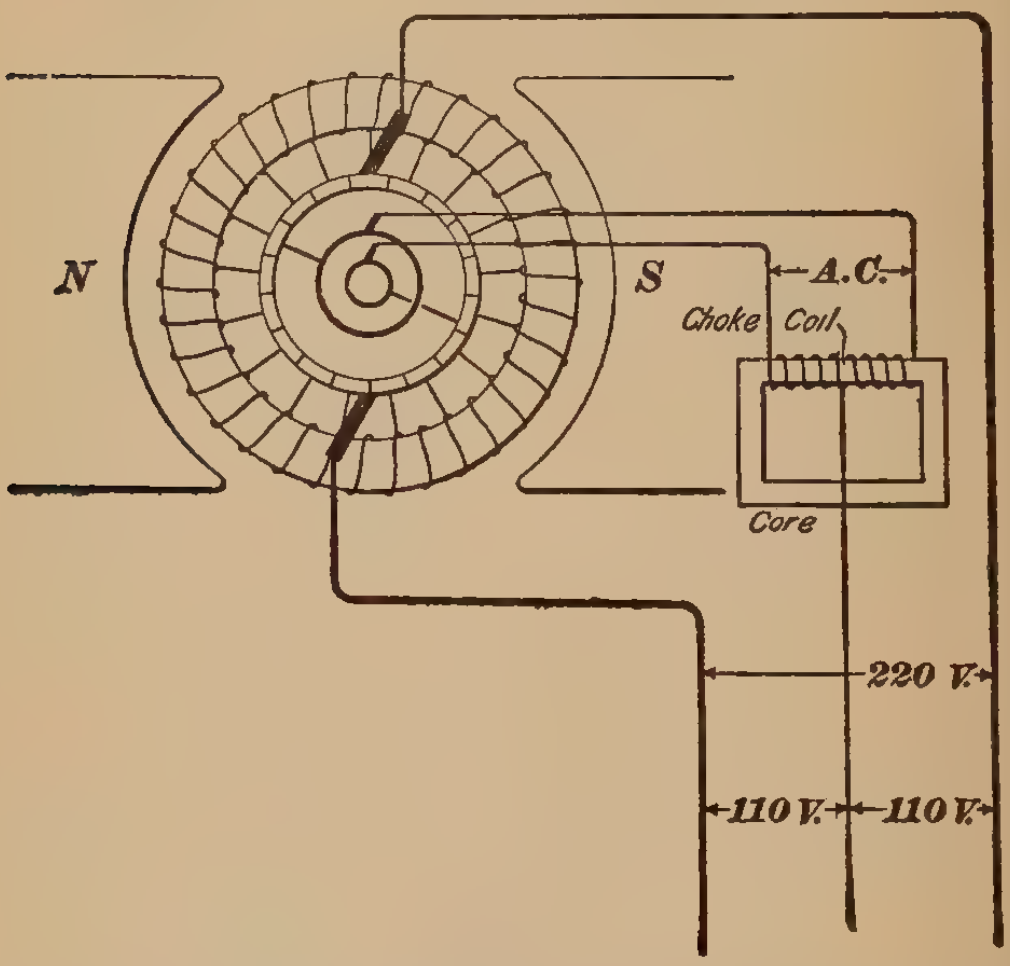


FIG. 13. THREE-WIRE DYNAMOS

wire of a three-wire system is connected to the middle point of the choke coil, the E. M. F.'s between the neutral wire and the two outside wires will always be approximately the same. Fig. 13 shows the connections. Owing to its self-induction, the choke coil will permit only a very small alternating current to flow between the two rings, but direct current readily passes to or from the neutral wire.

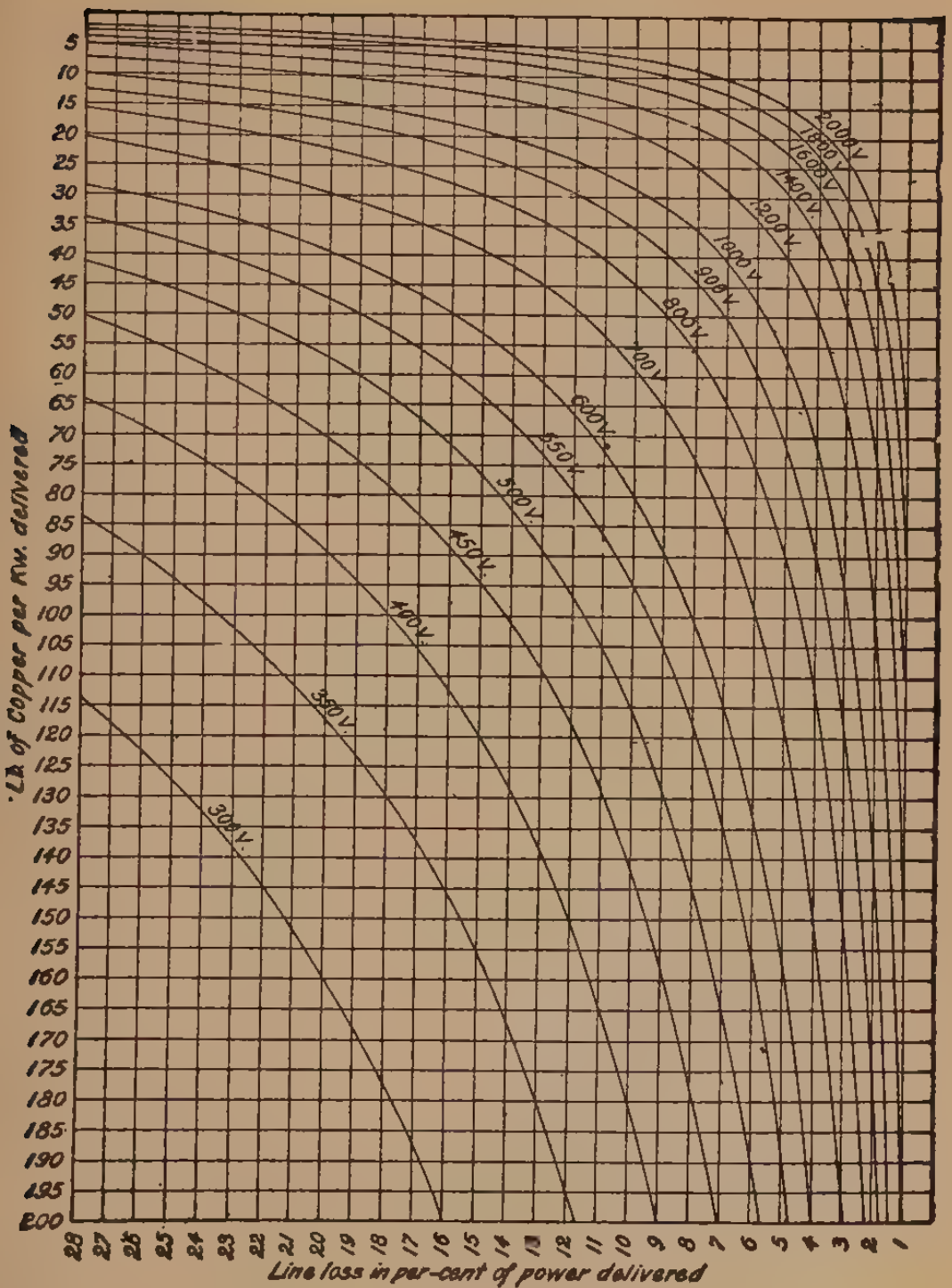


FIG. 14. WEIGHT OF COPPER FOR THREE-PHASE TRANSMISSION

Single dynamos with balancing sets or dynamos built on the Dobrowolsky plan are now generally installed for three-wire systems in preference to two dynamos.

LINE CONDUCTORS FOR ALTERNATING CURRENT

The size of the conductor for economical transmission depends on the strength of current; hence, a given quantity of energy can be transmitted much cheaper at high pressure than at low pressure. On account of the readiness with which alternating E. M. F.'s may be transformed up and down by means of step-up and step-down transformers, nearly all long-distance transmission is by alternating current.

To transmit a given quantity of energy with a given per cent. drop of potential and a given loss, the weight of the conductor varies inversely as the square of the voltage and directly as the square of the distance. Each of the curves in Fig. 14 is plotted for a different number of volts per mile; that is, total volts delivered at the end of the line divided by the number of miles. The curves are correct only for three-phase current with 100% power factor. For two-phase, single-phase, or continuous-current, one-third more copper is required; 5% has been allowed for sag and waste in weights.

If alternating current is to be transmitted for short distances, say 1 or 2 mi., and if the load is non-inductive—incandescent lamps for example—the conductors may be determined by the same methods as used for direct-current conductors; but for long distances or for loads causing power factors less than 1, the effect of capacity and self-induction must be considered.

In direct-current transmission, the percentage drop of pressure is the same as the percentage loss of power, but in alternating-current transmission, the percentage drop, when the power factor is less than 1, is greater than the percentage loss. This is because the current is greater than

VALUES OF CONSTANTS T AND t

Kind of System	Power Factor (Approximate)	T	t
Single-phase, operating incandescent lamps only	.95	1.052	2,400
Single-phase, operating incandescent lamps and motors	.85	1.176	3,000
Single-phase, operating motors only	.80	1.250	3,380
Two-phase, four-wire, operating incandescent lamps only	.95	.526	1,200
Two-phase, four-wire, operating incandescent lamps and motors	.85	.588	1,500
Two-phase, four-wire, operating motors only	.80	.625	1,690
Three-phase, three-wire, operating incandescent lamps only	.95	.607	1,200
Three-phase, three-wire, operating incandescent lamps and motors	.85	.679	1,500
Three-phase, three-wire, operating motors only	.80	.725	1,690

proportional to the real watts by the ratio cos ϕ (the power factor); that is, the real watts are EI cos ϕ, while the apparent watts are EI.

If the power in watts delivered by the line is represented by W, the volts delivered by E, the distance in feet one way by D, and the per cent. of the delivered power lost in the line by P, then the following formulas give very nearly correct results:

$$\text{Current in amperes} = \frac{W}{E}T$$

$$\text{Area of conductor section in circular mils} = \frac{DW}{PE^2}t,$$

in which P is always expressed as a whole number and T and t are constants, as given in the accompanying table.

For example, if it is desired to deliver 300 H. P. by means of 4,000-volt, three-phase current to motors 5 mi. away with a loss of 10% of the delivered power,

$$\text{current} = \frac{300 \times 746}{4{,}000} \times .725 = 40.6 \text{ amperes in each line wire,}$$

and

$$\text{circular mils} = \frac{5 \times 5{,}280 \times 300 \times 746}{10 \times 4{,}000 \times 4{,}000} \times 1{,}690 = 62{,}407,$$

or about No. 2 B. & S. wire.

Estimation of Line Drop.—The drop in a line with alternating current is greater than with the same strength of direct current by a factor M, the value of which depends on the frequency, the power factor, and the size of the line wire. If P is the per cent. drop with direct current and E the volts delivered, the approximate drop with alternating current is

$$e_a = \frac{PE}{100}M$$

EXAMPLE.—600 K. W. of 3-phase, 60-cycle current is to be delivered at 6,000 volts to a mixed load of motors and lights 6 mi. from the power station with a loss of 10% of the delivered power. Calculate (*a*) the current in each line wire; (*b*) the size of line wires; and (*c*) the volts drop in the line.

SOLUTION.—$W = 600{,}000$ watts; $D = 6 \times 5{,}280 = 31{,}680$ ft.; $T = .679$; $t = 1{,}500$; $P = 10$; and $E = 6{,}000$.

RATIO (M) OF ALTERNATING-CURRENT DROP TO DIRECT-CURRENT DROP

No. of Wire B. & S.	Area Circular Mils	30 Cycles			60 Cycles			125 Cycles		
		Lamps Only	Motors and Lamps	Motors Only	Lamps Only	Motors and Lamps	Motors Only	Lamps Only	Motors and Lamps	Motors Only
0000	211,600	1.26	1.27	1.24	1.64	1.85	1.85	2.44	3.06	3.14
000	167,805	1.20	1.17	1.14	1.49	1.63	1.62	2.15	2.62	2.67
00	133,079	1.15	1.08	1.05	1.39	1.46	1.42	1.92	2.25	2.29
0	105,534	1.10	1.00	1.00	1.30	1.32	1.28	1.73	1.96	1.99
1	83,694	1.06	1.00	1.00	1 23	1.21	1.16	1.57	1.74	1.73
2	66,373	1.03	1.00	1.00	1.16	1.11	1.06	1.44	1.54	1.53
3	52,634	1.02	1.00	1.00	1.11	1.04	1.00	1.35	1.38	1.38
4	41,742	1.00	1.00	1.00	1.07	1.00	1.00	1.26	1.26	1.22
5	33,102	1.00	1.00	1.00	1.04	1.00	1.00	1.19	1.16	1.11
6	26,250	1.00	1.00	1.00	1.02	1.00	1.00	1.14	1.08	1.03
7	20,816	1.00	1.00	1.00	1.00	1.00	1.00	1.09	1.01	1 00
8	16,509	1.00	1.00	1.00	1.00	1.00	1.00	1.06	1.00	1.00

(*a*) Current $= \frac{600{,}000}{6{,}000} \times .679 = 67.9$ amperes. **Ans.**

(*b*) Circular mils $= \frac{31{,}680 \times 600{,}000}{10 \times 6{,}000^2} \times 1{,}500 = 79{,}200$

or about No. 1 B. & S. wire. Ans.

(*c*) For No. 1 wire, 60 cycles, and a combined lamp and motor load, $M = 1.21$; hence,

$$e_s = \frac{10 \times 6{,}000}{100} \times 1.21 = 726 \text{ volts.} \quad \text{Ans.}$$

The foregoing methods are not exact, but will usually give practical results.

Polyphase Lines.—A two-phase, four-wire transmission line, if so arranged that there is no inductive interaction between circuits, is equivalent, so far as loss and regulation are concerned, to two single-phase lines, each carrying one-half the total energy. The same rule applies to a three-phase, three-wire circuit with conductors symmetrically arranged, and is practically correct for a two-phase, three-wire circuit. Therefore, in laying out any of these systems, calculate first a single-phase circuit to carry one-half the load at the given voltage, and then use four such wires instead of two for a four-wire, two-phase circuit, and three wires instead of two for a three-wire, three-phase circuit, in all cases keeping the distance between wires the same as obtained for the single-phase circuit.

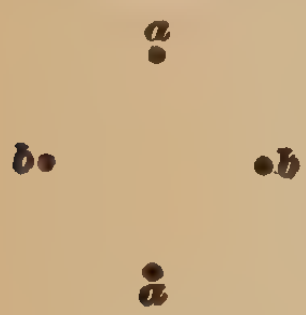


FIG. 15

FIG. 16

To make the circuit of two-phase, four-wire lines inductively independent, the wires of the two circuits must be arranged either as shown in Fig. 15—that is, wires a, a of one phase on opposite ends of one diagonal of a square, and wires b, b of the other phase on the ends of the other diagonal—or the wires of one phase must be transposed at their middle point, as shown in Fig. 16, so that the mutual inductive effect of one half is neutralized by the opposite effect of

the other half. The three wires of a three-phase line are usually arranged in the form of an equilateral triangle, as in Fig. 17; they may, however, be arranged in one plane and transposed at one-third and at two-thirds of the transmission distance, as shown in Fig. 18. On a long line, the transpositions shown in Figs. 16 and 18 should be repeated between each two points where power is taken off.

FIG. 17

FIG. 18

If several triangularly arranged three-phase lines are adjacent to one another, one line can run straight through, provided those near it are transposed often enough to make the mutually inductive effects neutralize each other. If side by side, as in Fig. 19, where line *a* runs straight through, the next line *b* should be transposed twice, and line *c* eight times; the fourth line would be transposed twenty-six times, etc. The two circuits of a two-phase, three-wire transmission cannot be made inductively independent; the arrangement of the wires side by side and equidistant throughout their length without transposition is as good as any.

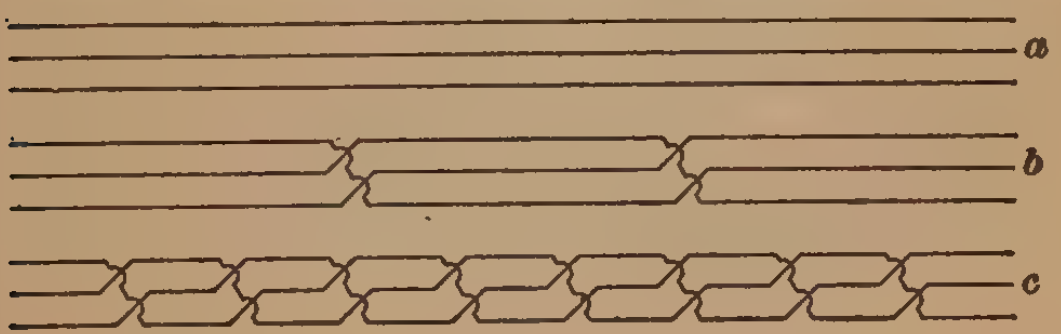


FIG. 19

Special arrangement to avoid inductive interaction is not necessary in short transmission lines, but unless it is done in long lines the system may become badly unbalanced and the drop and the losses may differ widely from calculations.

WIRES

CARRYING CAPACITY OF INSULATED WIRES

No wires smaller than No. 14 B. & S. can be used, except in fixtures or in flexible cords. The maximum permissible carrying capacities of various sizes of wires and cables are given in the accompanying tables. Wires selected with a view of keeping the voltage drop within practical limits are usually larger than required by the tables, but in no case must they

WIRES FOR MARINE WORK

(*National Code Standard*)

B. & S. Gauge Number	Area Actual Circular Mils	Number of Strands	Size of Strands B. & S. Gauge	Carrying Capacity Amperes
19	1,288			
18	1,624			3
17	2,048			
16	2,583			6
15	3,257			
14	4,107			12
12	6,530			17
	9,016	7	19	21
	11,368	7	18	25
	14,336	7	17	30
	18,081	7	16	35
	22,799	7	15	40
	30,856	19	18	50
	38,912	19	17	60
	49,077	19	16	70
Cables	60,088	37	18	85
	75,776	37	17	100
	99,064	61	18	120
	124,928	61	17	145
	157,563	61	16	170
	198,677	61	15	200
	250,527	61	14	235
	296,387	91	15	270
	373,737	91	14	320
	413,639	127	15	340

WIRES FOR INTERIORS OF BUILDINGS

(*National Code Standard*)

B. & S. Gauge Number	Circular Mils	Carrying Capacity	
		Rubber-Covered Wires Amperes	Weather-Proof Wires Amperes
18	1,624	3	5
16	2,583	6	8
14	4,107	12	16
12	6,530	17	23
10	10,380	24	32
8	16,510	33	46
6	26,250	46	65
5	33,100	54	77
4	41,740	65	92
3	52,630	76	110
2	66,370	90	131
1	83,690	107	156
0	105,500	127	185
00	133,100	150	220
000	167,800	177	262
0000	211,600	210	312
	200,000	200	300
	300,000	270	400
	400,000	330	500
	500,000	390	590
	600,000	450	680
	700,000	500	760
	800,000	550	840
	900,000	600	920
Cables	1,000,000	650	1,000
	1,100,000	690	1,080
	1,200,000	730	1,150
	1,300,000	770	1,220
	1,400,000	810	1,290
	1,500,000	850	1,360
	1,600,000	890	1,430
	1,700,000	930	1,490
	1,800,000	970	1,550
	1,900,000	1,010	1,610
	2,000,000	1,050	1,670

be smaller. Since rubber deteriorates if constantly heated, the carrying capacity of rubber-covered wire is slightly lower than that of weather-proof wire.

Joints.—There should be as few *joints*, or splices (Fig. 1), in the wires as possible. The insulation should be removed from the ends to be joined without cutting into the wire; the ends should be scraped until clean and bright, then twisted together until the joint is mechanically and electrically secure, after which it should be well soldered, and finally wrapped with insulating tape until the insulation of the joint is equal to that of the wires joined. The separate strands of stranded wires must be securely soldered together before fastening the wire under terminal clamps. All stranded wires with conductivity greater than that of No. 8 B. & S. gauge must be soldered into lugs for all terminal connections.

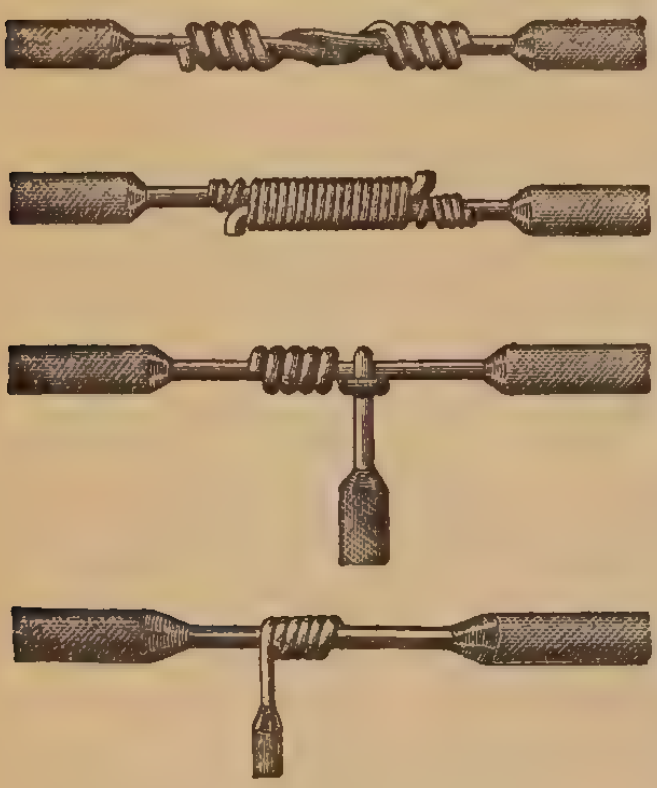


FIG. 1. WIRE JOINTS

The Code rules suggest the following formula for soldering fluid:

	PARTS
Saturated solution of zinc chloride	5
Alcohol	4
Glycerine	1

Miscellaneous Rules.—Unless wires are run in conduit or molding, they must be separated from all other objects by glass or porcelain insulators. Tie wires must have insulation equal to that of the wires tied. Wires must not be laid in plaster or cement, and twin wires are permitted

only in conduit. For open work in dry places, *slow-burning weather-proof wire* may be used; for all concealed work and in all damp places, the wires must be *rubber-covered*. Rubber-covered wires with an extra-heavy outside covering of tape or braid may be used in unlined metal conduit; if the conduit is lined, the outside covering on the wires is not required. Fixture wire must not be smaller than No. 18 B. & S. and must be rubber-covered.

Flexible cord must not be used where the E. M. F. exceeds 300 volts, nor to support clusters, nor in show windows. The cord must be protected by a bushing at the point where it enters a lamp socket. If used to support the weight of a lamp, a knot must be tied in the cord below the bushing and another above the ceiling rosette, so as to reduce the pull on the connecting screws.

CALCULATING SIZE OF WIRE

The feeder wires entering a building are usually led to one or more *centers of distribution*, from which the distribution, or branch, circuits go to the consuming devices. In wiring for incandescent lamps, the drop from the point where the feeders enter the building to the lamps should be not over 3 to 5% of the lamp voltage. This total drop can be divided between the feeders to the centers of distribution and the distribution circuits in the proportion of say 3 and 2; that is, 3% drop in the feeders and 2% drop in the distribution circuits.

Before calculating the size of wire, it is necessary to know the current I in amperes to be carried, the average distance D in feet one way, and the drop e in volts. So many varieties of incandescent lamps are now obtainable, operating at such different economies, that it is best to calculate the current I by the formula

$$I = \frac{NwC}{E},$$

in which N is the number of lamps, w the watts per candlepower, C the candlepower per lamp, and E the voltage of the lamps. The product wC, the watts per lamp, is often given instead of the separate factors. The distance should

CURRENT REQUIRED BY MOTORS

H. P.	Direct-Current Motors			Alternating-Current Motors								
				Single-Phase			Two-Phase (4 Wire)			Three-Phase (3 Wire)		
	110 V	220 V	500 V	110 V	220 V	500 V	110 V	220 V	500 V	110 V	220 V	500 V
1	9	4.5	2.0	14	7	3.1	6.4	3.2	1.4	7.4	3.7	1.6
2	17	8.5	3.7	24	12	5.3	11	5.7	2.5	13	6.6	2.9
3	26	13	5.6	34	17	7.5	16	8.1	3.5	19	9.3	4.1
5	40	20	8.8	52	26	11	26	13	5.5	30	15	6.4
7½	60	30	13	74	37	16	38	19	8.1	44	22	9.3
10	76	38	17	94	47	21	44	22	10	50	25	12
15	112	56	25				66	33	15	76	38	17
20	150	75	33				88	44	19	102	51	22
30	226	113	50				134	67	29	154	77	33
40	302	151	66				178	89	39	204	107	45
50	368	184	81				204	102	45	236	118	52
75	552	276	122				308	154	68	356	178	77
100	736	368	162				408	204	90	472	236	104
150	1,110	555	244				616	308	135	710	355	156
200	1,474	737	324				818	409	180	940	470	208

be an average of the distances to the various lamps on the circuit; for example, if a circuit is 150 ft. long with lamps distributed evenly over the last 50 ft., the distance D for which the wire should be calculated should be $100+\frac{50}{2}=125$ ft. The drop e in volts is obtained by multiplying the lamp voltage by the per cent. drop to be allowed.

CURRENT IN AMPERES REQUIRED BY MOTORS

The accompanying table gives the approximate current required by motors. These figures are close enough for wiring calculations, though the exact current in any case depends on the efficiency of the motor and, also, in case of alternating-current motors, on its power factor.

Knowing the distance D, the current I, and the drop e, the size of wire in circular mils (c. m.) is obtained from the formula

$$\text{c. m.}=\frac{21.6DI}{e}$$

EXAMPLE.—Calculate the size of wire necessary to supply current to eighty-four 22-c.-p., 2-watt, 110-volt lamps distributed evenly along 100 ft. of the circuit, the nearest lamp being 50 ft. from the center of distribution; permissible drop 2%.

SOLUTION.—The distance $D=50+\frac{100}{2}=100$ ft.; the current $I=\frac{84\times22\times2}{110}=33.6$ amperes; and the drop $e=.02\times110=2.2$ volts.

$$\text{c. m.}=\frac{21.6\times100\times33.6}{2.2}=33{,}000,$$

or about No. 5 B. & S. wire. Ans.

If, in the foregoing example, all the current traveled the whole length of the line, 150 ft., the size of the wire for 2% drop would be

$$\text{c. m.}=\frac{21.6\times150\times33.6}{2.2}=49{,}500,$$

requiring the use of No. 3 B. & S. wire.

WIRING TABLE

To use the accompanying wiring table, divide the number of amperes to be transmitted by the number of volts drop permissible and find the quotient thus obtained, or the number

WIRING TABLE

Size of Wire, B. & S. Gauge Number	Distance in Feet (One Way) Producing a Drop of 1 Volt for Given Currents and Given Sizes of Wire														
Amperes	1	5	10	15	20	25	30	35	40	45	50	60	70	80	90	100
18	75.2	15.0														
16	120.0	24.0	12.0	8.0												
14	190.0	38.0	19.0	12.7	9.5	7.6										
12	302.0	60.4	30.2	20.2	15.1	12.1	10.1	8.6								
10	480.0	96.0	48.0	32.0	24.0	19.2	16.0	13.7	12.0	10.7						
8	764.0	153.0	76 4	51.0	38.3	30.6	25.5	21.8	19.1	17.0	15.3	12.7				
6	1,215.0	243.0	121.5	81.0	60.8	48.6	40.5	34.7	30.4	27.0	24.3	20.3	17.4	15.2		
5	1,533.0	307.0	153.3	102.0	76.6	61.3	51.1	43.8	38.4	34.1	30.7	25.6	21.9	19.2	17.0	15.3
4	1,933.0	387.0	193.0	129.0	96.7	77.3	64.4	55.1	48.3	43.0	38.7	32.2	27.6	24.2	21.5	19.3
3	2,437.0	487.0	244.0	162.0	122.0	97.4	81.1	69.6	60.9	54.0	48.7	40.6	34.8	30.5	27.1	24.4
2	3,073.0	615.0	307.0	205.0	154.0	123.0	102.0	87.9	76.9	68.3	61.5	51.4	43.9	38.4	34.1	30.7
1		774.0	387.0	258.0	194.0	155.0	129.0	111.0	96.9	86.0	77.4	64.5	55.3	48.4	43.0	38.7
0		978.0	489.0	326.0	245.0	195.0	163.0	140.0	122.0	109.0	97.8	81.5	69.9	61.1	54.3	48.9
00		1,232.0	616.0	410.0	308.0	246.0	205.0	176.0	154.0	137.0	123.2	102.7	88.0	77.0	68.4	61.6
000			777.0	518.0	388.0	311.0	259.0	222.0	194.0	173.0	155.4	129.5	111.0	97.1	86.3	77.7
0000			980.0	653.0	490.0	392.0	326.0	280.0	245.0	218.0	196.0	163.3	140.0	122.5	108.9	98.0

nearest to it, in the line of amperes along the top of the table. In the column below the number thus found find the nearest distance, and to the left in the column of wires find the required size B. & S. gauge number. For example, to find the size of wire to transmit 15 amperes 140 ft. with 3 volts loss, divide 15 by 3 and find the quotient 5 (amperes per volt) in the line of amperes. In the column below, find the nearest distance 153, and to the left of this the size of wire required, which is No. 8.

CIRCUIT-OPENING DEVICES

Both a *switch* and an *automatic circuit opener* (cut-out or circuit-breaker) must be placed in every supply circuit near where it enters a building, so that all the current can be cut off from the building. Except where expert supervision is maintained, circuit-breakers are not permitted unless accompanied by fuses.

Circuit-opening devices must not be installed near combustible materials nor where exposed to inflammable gases or dust. In damp places and in places where flying particles of inflammable material are present, the switches and cut-outs must be in dust- and moisture-proof cabinets, which must have self-closing doors if dust is also present.

On constant-potential circuits, the switches and cut-outs must be capable of opening all the wires of the circuit, except that single-pole switches may be used if the circuit uses less than 660 watts at not over 300 volts. No single-pole cut-out can be used to control more than 660 watts, except where all the power is used in a single device, as in a motor.

Cut-outs must be installed at each point where a change is made in the size of wire unless the cut-out in the larger wire is small enough to protect the smaller wire. The capacity of the fuses must be such that they will melt, or blow, if the current exceeds the safe carrying capacity of the wires. Circuit-breakers must be set to open if the current exceeds the safe carrying capacity of the wires by 30%, unless fusible cut-outs are also used to protect the same wires. Fuses must not be placed in the canopies or shells

of fixtures. Except on slate or marble tablet boards mounted in dust-tight, fireproof cabinets, open-link fuses are not allowed; enclosed fuses are demanded instead.

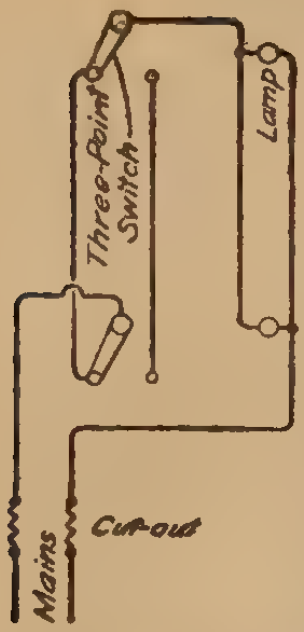


FIG. 2

A switch cabinet should be installed at each center of distribution, and in it should be placed a switch and a cut-out for each branch circuit. A convenient wall switch should also be installed for each large chandelier or group of lamps, unless the distribution cabinet is within easy reach. Two three-point switches connected, as shown in Fig. 2, so that one or more lights can be controlled from more than one point are often very convenient; for example, the hall lights in a dwelling house may be controlled from either floor by means of two three-point switches. By means of two three-point switches and one four-point switch, wired as in Fig. 3, the same lights may be controlled from three points, etc. By introducing another four-point switch for each station, this scheme may be extended.

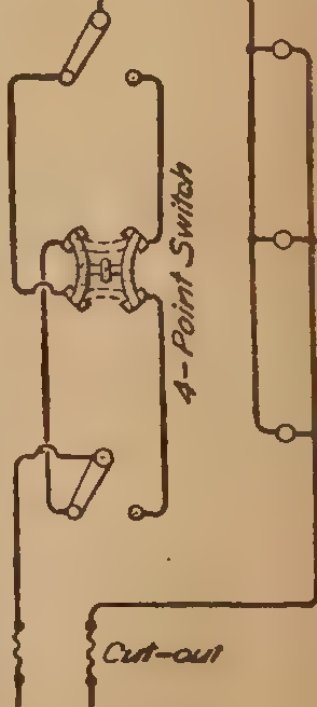


FIG. 3

Single-throw knife switches must be mounted so that gravity will tend to open them and, when possible, so that the blades will be dead when the switch is open. Double-throw knife switches may be mounted so that the throw will be either vertical or horizontal. For circuits using less than 250 volts and 30 amperes, approved snap switches are better than knife switches, but they should indicate plainly whether the current is *on* or *off*. Flush switches must be contained in a sheet-steel or cast-iron box set in the wall

SYSTEMS OF INSTALLATION

OPEN WORK

Open Work in Dry Places.—For open work in *dry places*, or for protection against corrosive vapors, slow-burning, weather-proof insulation is permissible. The wires must be held at least ½ in. from the surfaces wired over and 2½ in.

FIG. 4. KNOB

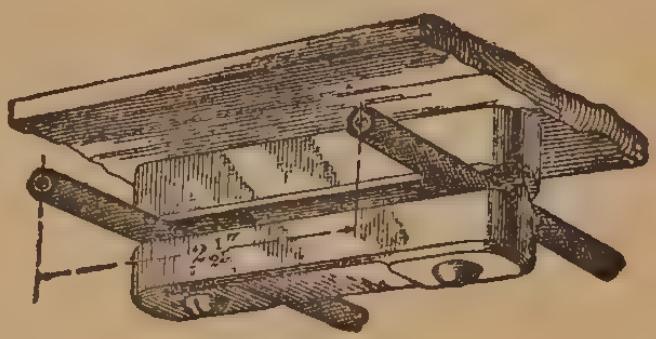


FIG. 5. CLEATS

apart for voltages up to 300, and 1 in. from the surface and 4 in. apart for voltages from 300 up to 550. The wires must be held on insulators or by cleats, Figs. 4, 5, and 6, and must be protected by insulating tubes, Fig. 7, when passing through floors or partitions, so that the wires come in contact with nothing except insulating supports or protectors. The insulators and tubes used must be non-combustible and non-absorptive; porcelain is the material nearly always used.

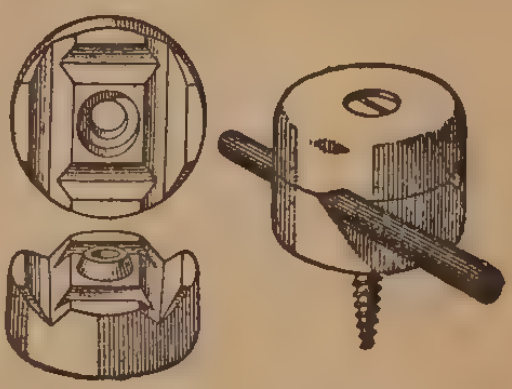


FIG. 6. KNOB CLEATS

On straight runs, the supports should be as close as every 4½ ft. In buildings of mill construction (see Fig. 8) mains of No. 8 B. & S. wire or larger, if not likely to be disturbed, may be separated about 6 in. and run across the ceiling by tying them to insulators attached to the timbers

if likely to be disturbed or if smaller than No. 8 B. & S. wires are used, they should be run around or through the ceiling timbers, with suitable insulators or protecting tubes, or should be attached to insulators fastened to running boards.

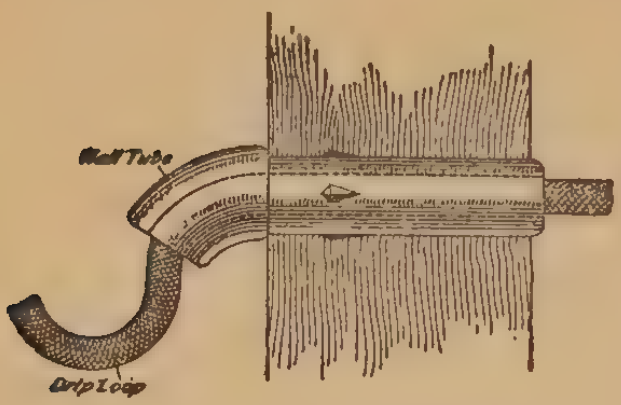


FIG. 7. WALL TUBE

When two wires cross each other, one of them should be run through an insulating tube so fastened that it cannot slide away from the crossing, as in Fig. 9. The same method may be

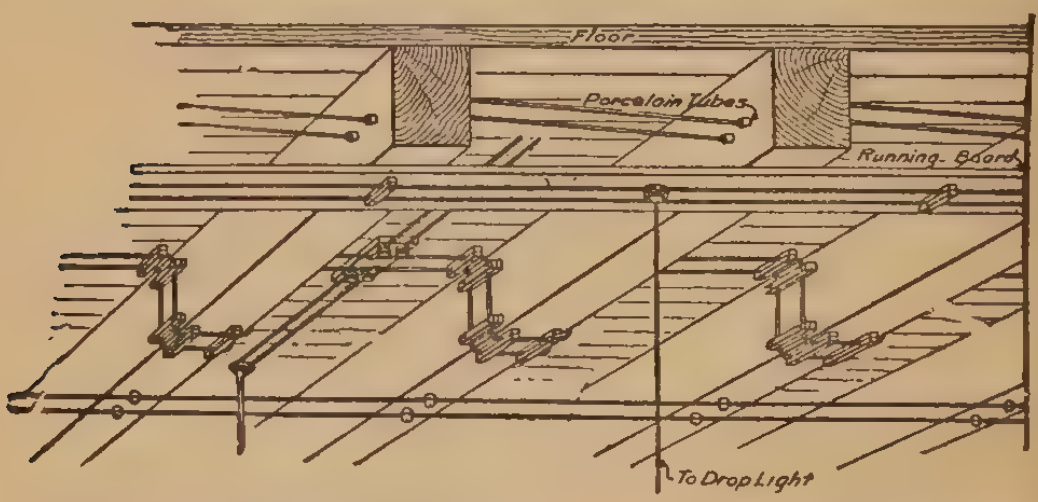


FIG. 8. METHODS OF WIRING OVER CEILING TIMBERS

used when passing near iron pipes. Wires should pass over pipes on which moisture may collect.

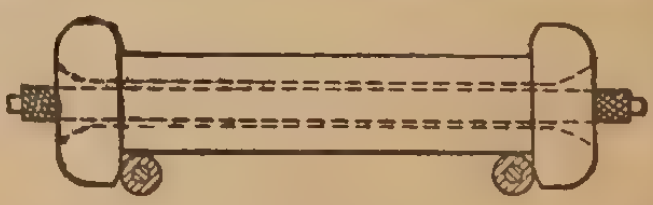


FIG. 9

Open Work in Damp Places.—In *damp places*, rubber-covered wire is required. The insulating supports and tubes are the same as used in dry places, but the wires must be at least 1 in. from the surface wired over.

Constant-Current Systems.—Wires for constant-current systems, where arc or incandescent lamps are in series, must be rubber-covered, and in each case must enter and leave the building through a switch that will cut off the current from the building and close the main circuit simultaneously. The switch must be mounted on a non-combustible base, where it will be free from moisture and within easy reach. The wires must always be in plain sight, supported on glass or porcelain insulators at least 1 in. from the surface wired over and 8 in. from each other, except in the lamps, on hanger boards, etc.

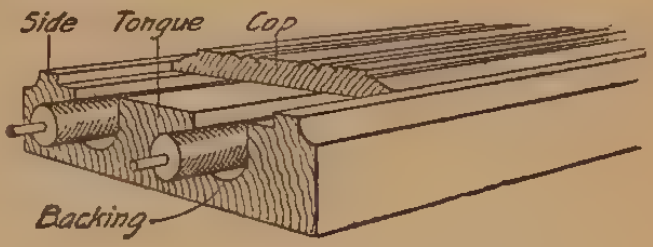


FIG. 10. WOODEN MOLDING

CONCEALED WORK

All conductors for concealed wiring must be rubber-covered.

Wooden molding, Fig. 10, for encasing wires must have a backing at least $\frac{3}{8}$ in. thick under the wires; the tongue between the wire grooves must be at least $\frac{1}{2}$ in. thick, and the sides at least $\frac{1}{4}$ in. thick. The inside of the molding and the cap must have at least two coats of waterproof material, or else the whole molding must be impregnated with moisture repellant. Wooden molding must not be used in concealed or damp places, nor be placed directly against a brick wall where sweating may introduce moisture that may ultimately cause a short circuit. Wooden molding for concealing electrical conductors is prohibited by ordinances in some cities.

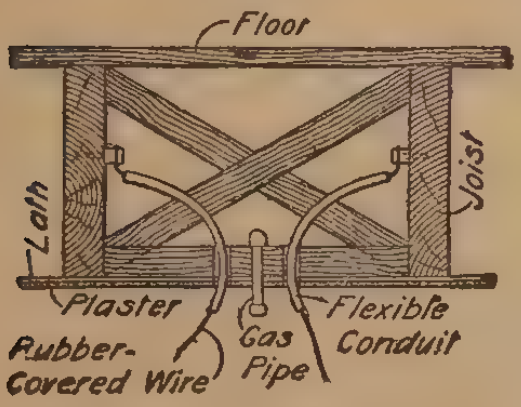


FIG. 11. CEILING OUTLET

Concealed knob-and-tube work is permitted by the Underwriters' rules, though forbidden by ordinances in some large cities. It is a cheap form of concealed wiring, and safe if properly installed. In running lengthwise of joists, each wire should run along a separate joist and be securely fastened to knobs not over 4½ ft. apart, and less if there is any likelihood of disturbance. Where the wires pass

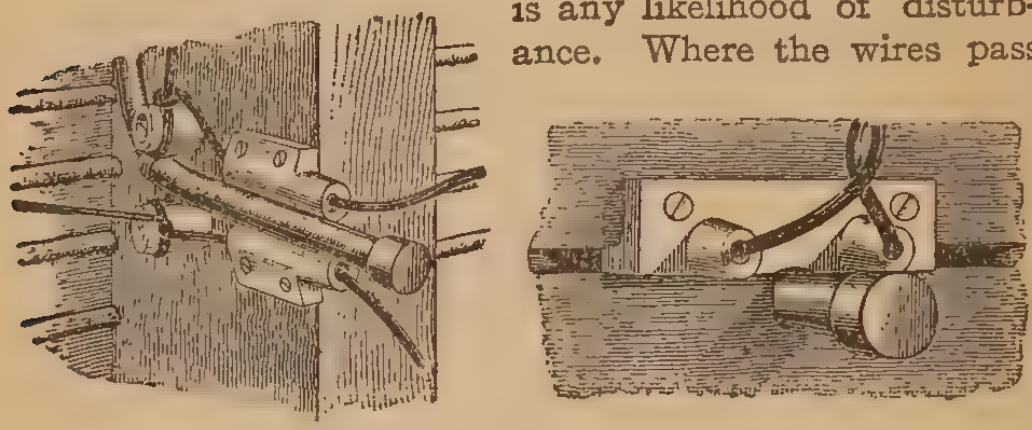


FIG. 12. WALL OUTLETS

through joists, they should be protected by porcelain bushings projecting at least ½ in. beyond the timber on each side.

At outlets, Figs. 11 and 12, the insulation must be particularly good. The wires should be protected by flexible conduit or insulating tubing, so that they cannot come in contact with the plaster, gas pipe, etc. Flexible circular-loom tube is very useful for this purpose. This is a woven tube without metal covering, and is treated outside and inside with insulating material that makes it hold its shape; this tube is neither weather-proof nor nail-proof, and is permitted only in dry and well-protected places. Flexible steel-armored cable,

FIG. 13. STEEL-ARMORED CABLE

Fig. 13, makes a convenient auxiliary for the concealed knob-and-tube system, and is used throughout many large buildings where there is no risk from moisture. If moisture is present, this cable must be covered with a lead sheathing.

Conduit wiring is the best and most expensive kind of concealed wiring, and the only kind permitted in fireproof

structures. Iron pipe not less than ⅝ in. inside diameter, either lined with insulation or unlined, is installed wherever circuits are to run, so as to form a continuous raceway for the wires. After all the pipes are in place and all mechanical work on the building is so

FIG. 14
STEEL-ARMORED CONDUIT

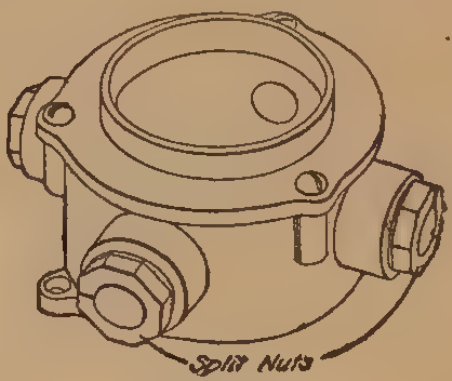


FIG. 15
OUTLET BOX

nearly complete that there is no danger of disturbing the wires, they are fished through the conduit from outlet to outlet. The two or more wires of a circuit are usually drawn through the same conduit; this is required by the Code rules if alternating current is to be used. The

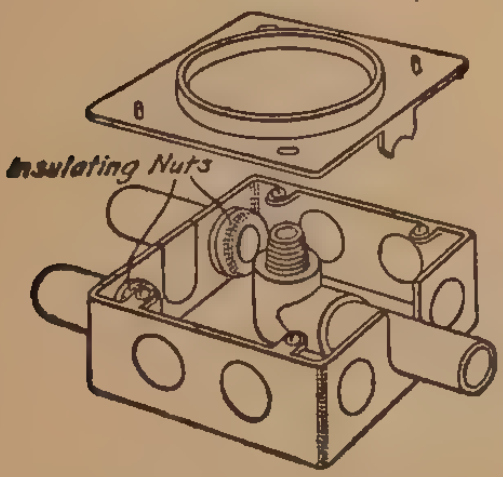


FIG. 16. OUTLET BOX

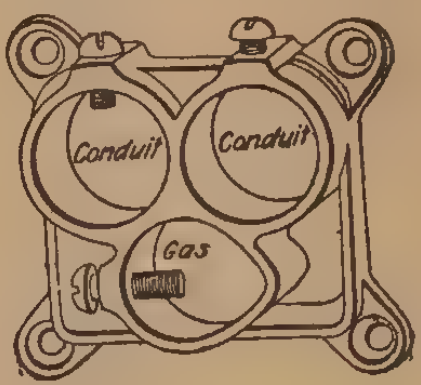


FIG. 17. OUTLET PLATE

conduit system must be in continuous electrical connection, by bonding around outlet boxes if necessary, and must be effectually grounded. The radius of the inner edge of all

bends must not be less than 3½ in. and there must not be more than an equivalent of four quarter bends from outlet to outlet, not counting the bends at the outlet.

The *fishing* is done with a long piece of steel ribbon, called a *snake;* this ribbon is about ⅛ in. wide and $\frac{1}{16}$ in. thick, and has a steel ball about ¼ in. in diameter fastened to one end Soapstone is first blown into the conduit to overcome friction; the ball end of the snake is then pushed through

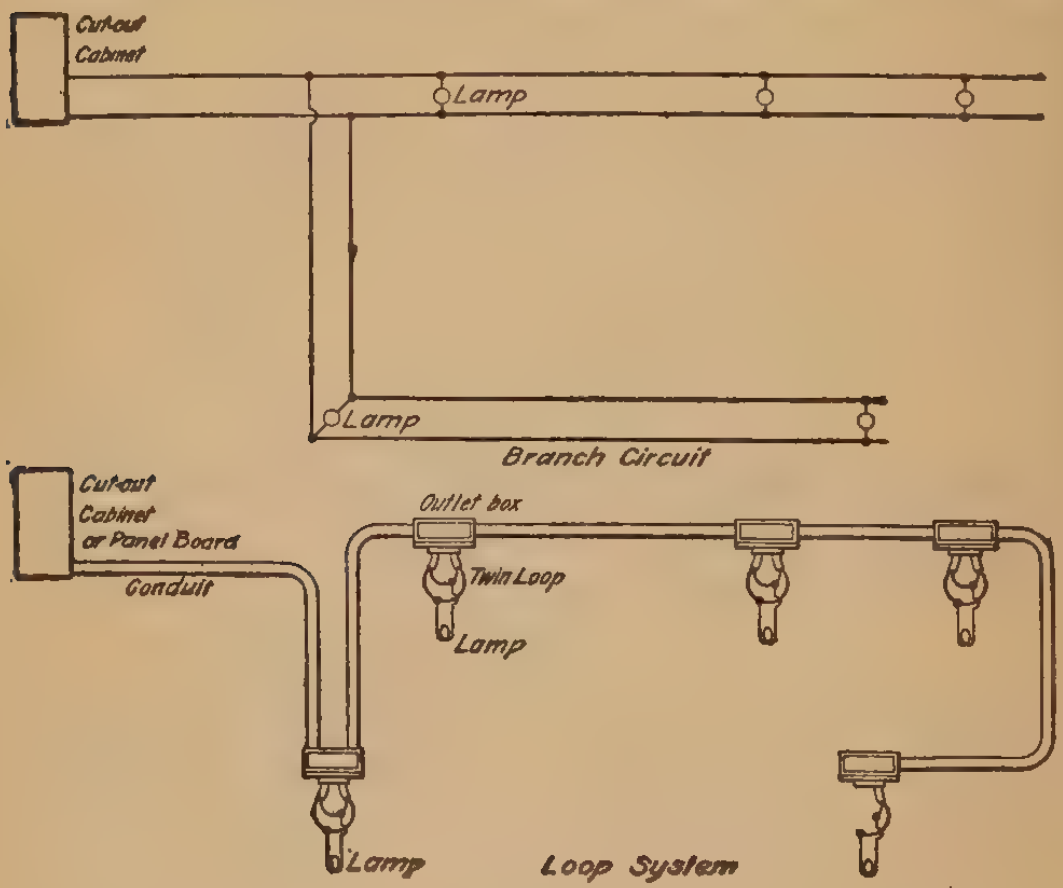


FIG. 18

from one outlet to another, a cord is attached and drawn through, and the wires are then drawn in.

Instead of iron pipe, flexible steel-armored conduit, Fig. 14, is sometimes used; this can be easily bent around curves without the necessity of screw joints. The easy curves offer little resistance to the entrance of the wires.

Outlet and *junction boxes* are made in great variety. In one type. Fig. 15, the conduit is held in place by split nuts,

which close around the conduit and clamp it securely when they are screwed home. In another type, Fig. 16, the conduit ends are threaded and held in place by insulating nuts outside and inside the box. Junction boxes should be installed where they are easily accessible.

Outlet plates, Fig. 17, are permitted where it is not feasible to use boxes.

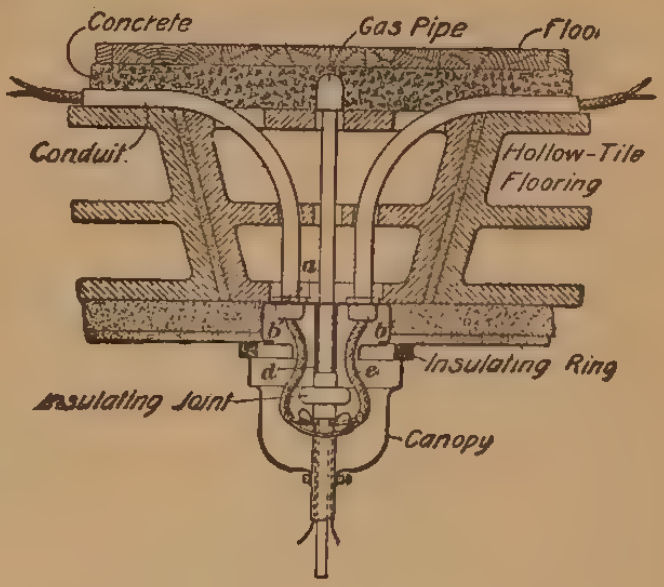


FIG. 19. CEILING OUTLET

Joints are especially objectionable in wires used in conduits, and are not made except where a junction box cannot be installed. In order to avoid branch circuits with their necessary joints, conduit wires are usually installed on the *loop system*, as shown in the lower half of Fig. 18; that is, both wires are looped to each lamp; they are then easily withdrawn from the conduit.

A *ceiling outlet* in a fireproof building, Fig. 19, may be made by bringing the conduit down through the hollow-tile flooring to the outlet box *a*, to which it is fastened with insulating nuts *b*. If gas also is used, the gas pipe is run into the same box and is covered by an insulating bushing *d*. The fixture is fastened to the end of the gas pipe with an insulating joint. The two-wire cable *e* is brought down on the loop

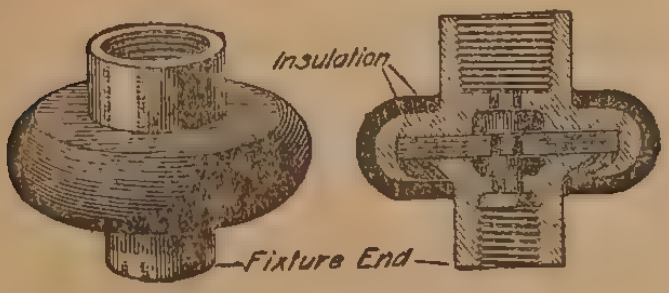


FIG. 20. INSULATING JOINT

system, and the fixture wire is connected to it. An *insulating joint* is shown in Fig. 20.

For *wall outlets* in a fireproof structure, Fig. 21, the conduit should be installed between the wooden strips to which the laths are nailed. The outlet box can be fastened to a brick wall with expansion bolts or by screwing it to wooden plugs driven into holes drilled into the brick; the fixture is then screwed into a threaded stud fastened to the back of the outlet box.

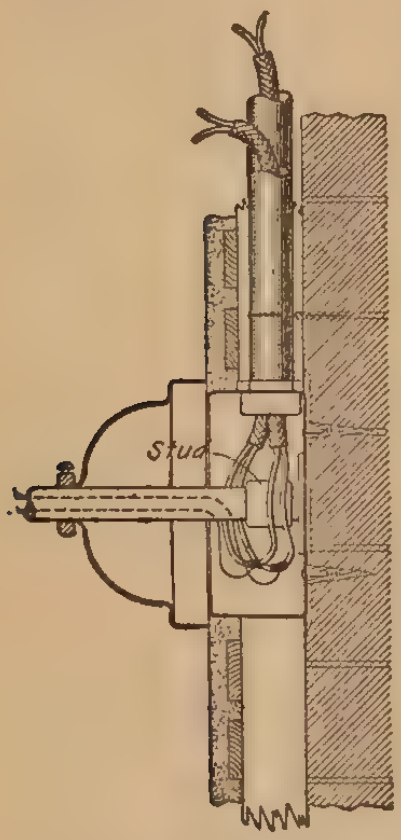


FIG. 21. WALL OUTLET

WIRING FOR MINOR ELECTRIC APPLIANCES

The source of E. M. F. for ringing bells, operating burglar alarms, door openers, electric clocks, etc., may be primary or secondary batteries, a small dynamo, or the electric-lighting circuit. The rules for the installation of electric-light and electric-power wires do not apply to such minor systems, unless the E. M. F. used exceeds 10 volts, or unless the circuits are in electrical contact with the lighting circuits.

Primary batteries most used for such systems are of the open-circuit variety, such as the ordinary sal-ammoniac cells. Two storage batteries, each with a double-throw switch, can be arranged, as in Fig. 22, so that one can be charged while the other is in use. For bell ringing, a series of lamps can be used across the lighting circuit, as in Fig. 23. If the bell is connected in series with the lamps, its contact device makes and breaks the full lighting voltage, and is likely soon to be injured; a better plan is to connect the bell in shunt with one of the lamps.

The wire used inside buildings for bells, burglar alarms, gas lighting, etc., is usually No. 16 or No. 18 B. & S.; or in large

systems, No. 14 is used for the main-battery wire. For dry

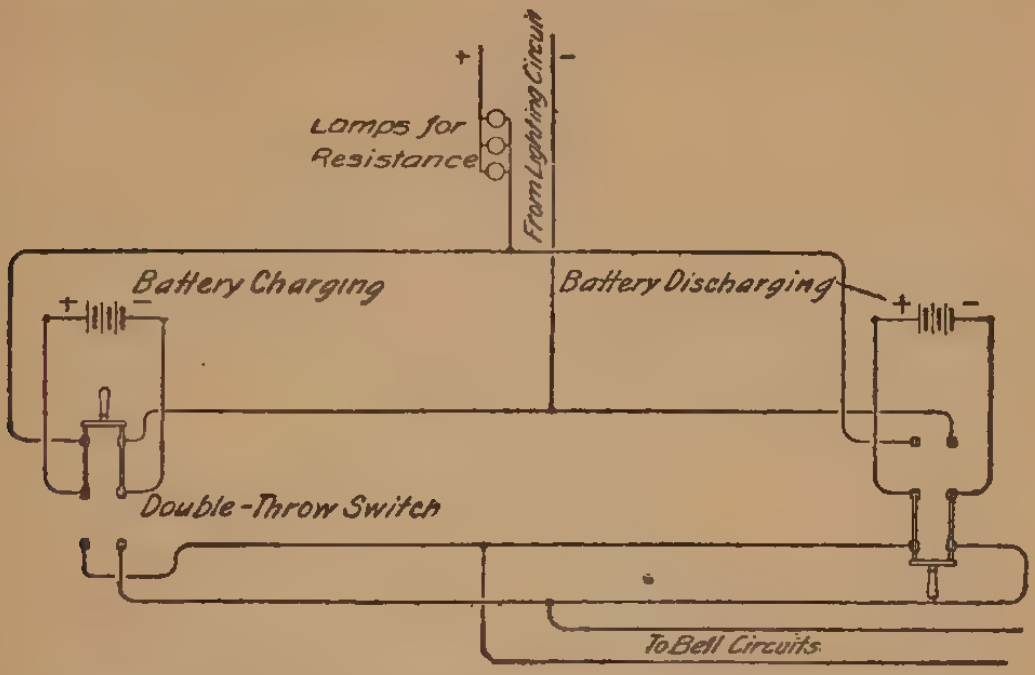


FIG. 22. STORAGE BATTERIES FOR BELL RINGING

places, double-cotton paraffined insulation is good enough;

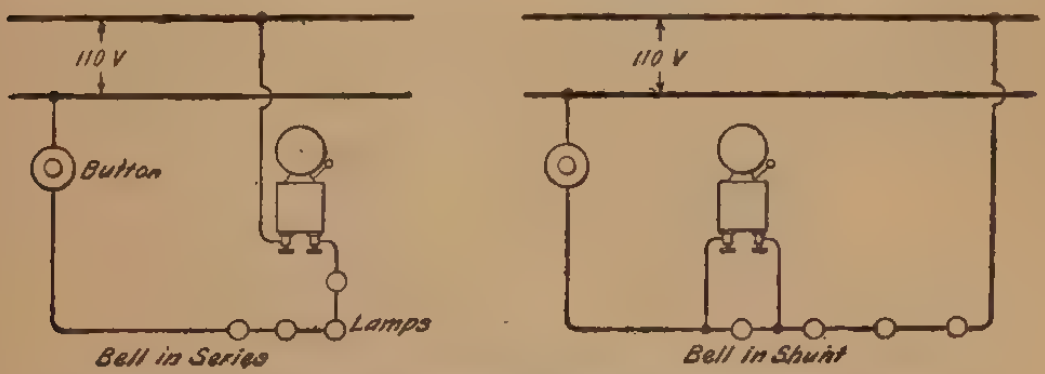


FIG. 23. BELL RINGING FROM LIGHTING CIRCUIT

weather-proof office wire should be used in damp places, or rubber-covered wire if much moisture is present.

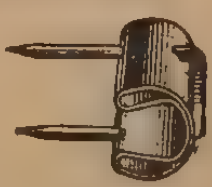


FIG. 24

The wires should be neatly arranged and securely fastened. Single wires can be fastened to woodwork with bare iron staples, or, if the staples are insulated, as in Fig. 24, two or more wires may be fastened under one staple;

but in no case should the staples be driven hard. Bell wires must not be placed less than 6 in. from any electric-light

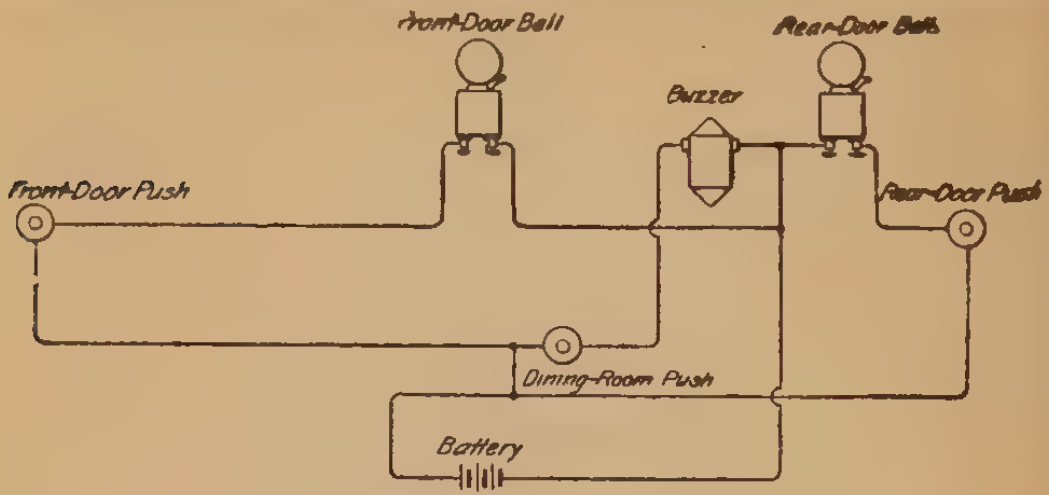


FIG. 25. SIMPLE BELL-WIRING CIRCUITS

or electric-power wire unless encased in approved tubing. When bunched together, bell wires must have a fire-proof covering or else be incased in a non-combustible tube, or

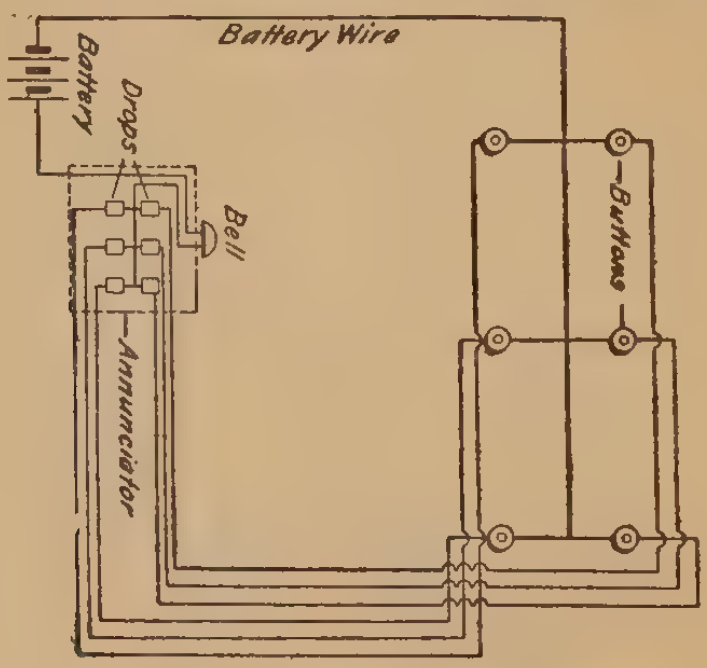


FIG. 26. ANNUNCIATOR SYSTEM

shaft. In the best class of work, all bell wires are run in conduits. Vertical wire ducts, or shafts, must be thoroughly

stopped at each floor, so that they cannot serve as flues to assist the spread of fire. Push buttons and electric-light switches must not be mounted on the same wall plate. All circuits when complete should be tested for breaks, grounds, or crosses. These tests can be made with an ordinary magneto bell.

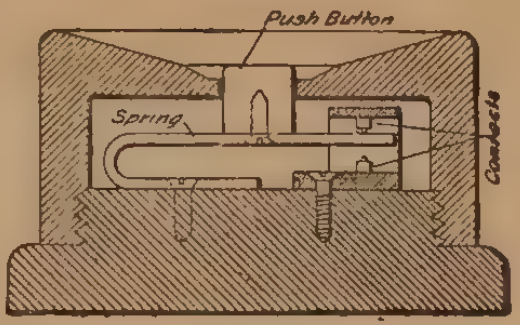


FIG. 27

BELL CIRCUITS

In a small dwelling, the bell wires may be arranged as in Fig. 25. An annunciator is seldom necessary, since the bells at the front and back doors and the buzzer in the kitchen, to be sounded from the

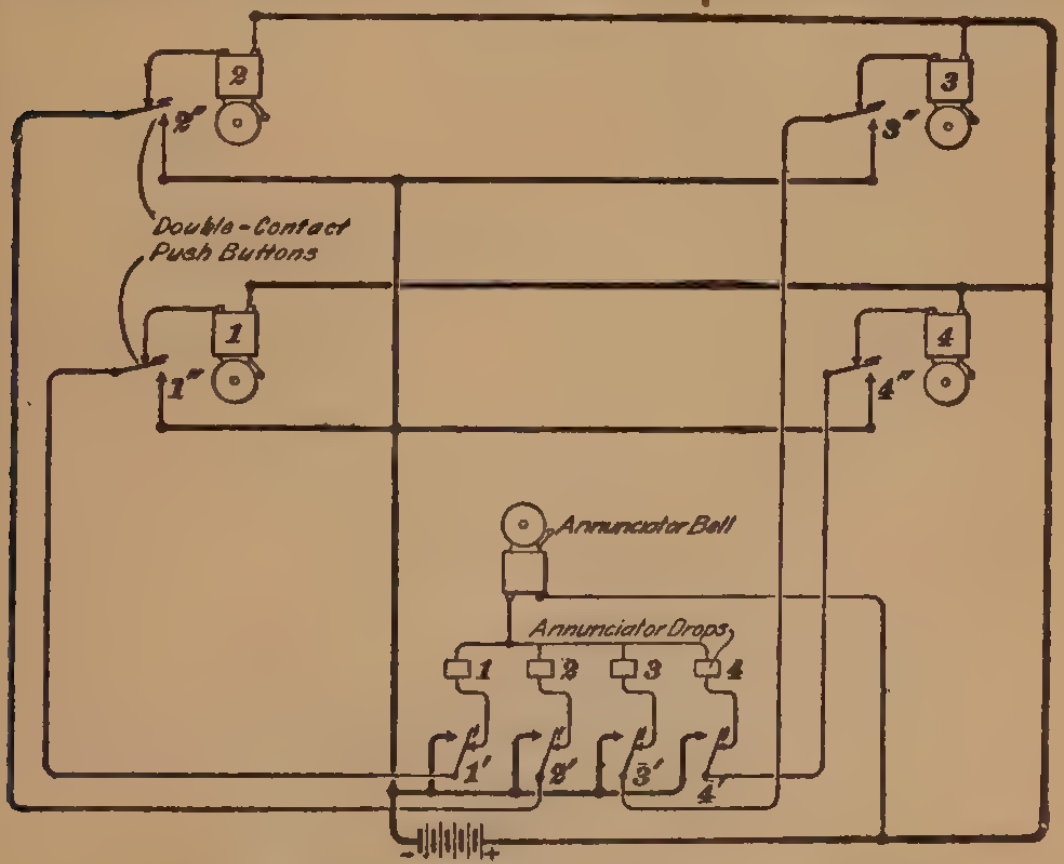


FIG. 28. RETURN-CALL SYSTEM

dining room, may be selected so that each has a distinctive sound.

In an *annunciator system*, Fig. 26, the buttons are located at convenient points, each button being arranged to close a circuit from the battery through the annunciator bell and a drop.

By means of double-contact push buttons, Fig. 27, *return-call annunciator systems* are arranged, as shown in Fig. 28. A bell in any room of a large hotel may be rung by pressing a double-contact push button in the office, or the office annunciator bell may be rung from any room.

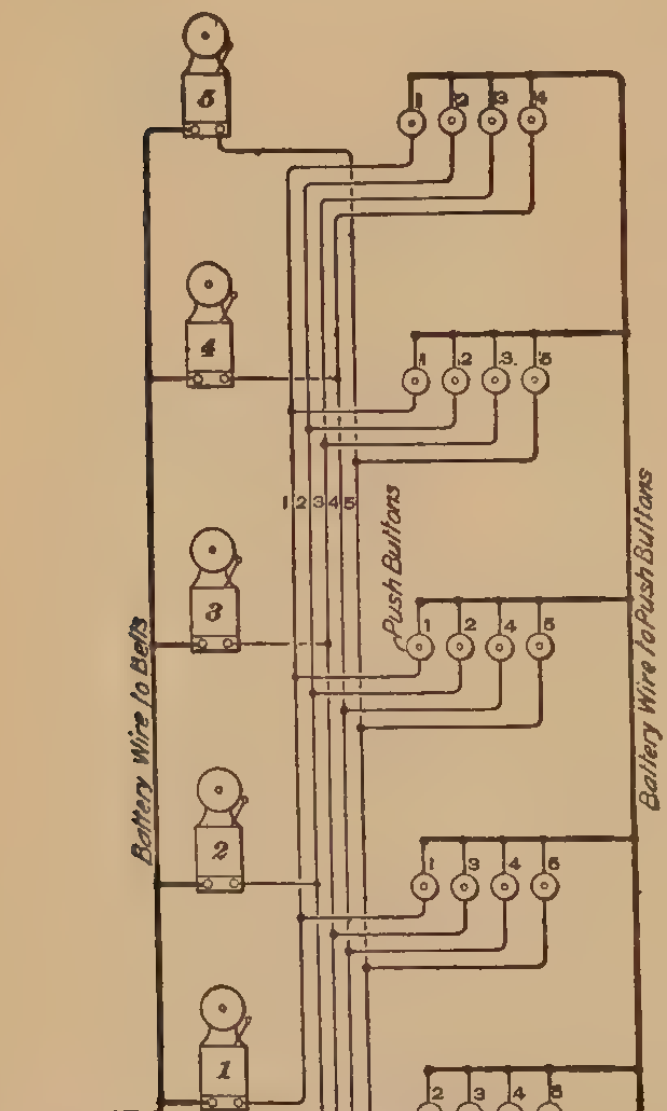


FIG. 29. SPEAKING-TUBE SYSTEM

Fig. 29 shows a diagram of the bell wiring for a *speaking-tube system*. From each station may be rung any bell except its own.

Fire-alarm gongs in large buildings can be wired, as in Fig. 30, so that all the gongs can be rung simultaneously by pressing a multiple-contact push button. An annunciator near each bell will at the same time reveal the source of the signal. The battery is better subdivided, with a section placed near each bell; but, if desired, it can all be placed at one location in the circuit.

Wiring Flats.—Several flats may be wired, as in Fig. 31, so that a single battery may be used to ring a bell in each flat from a push button at the front door of the building or

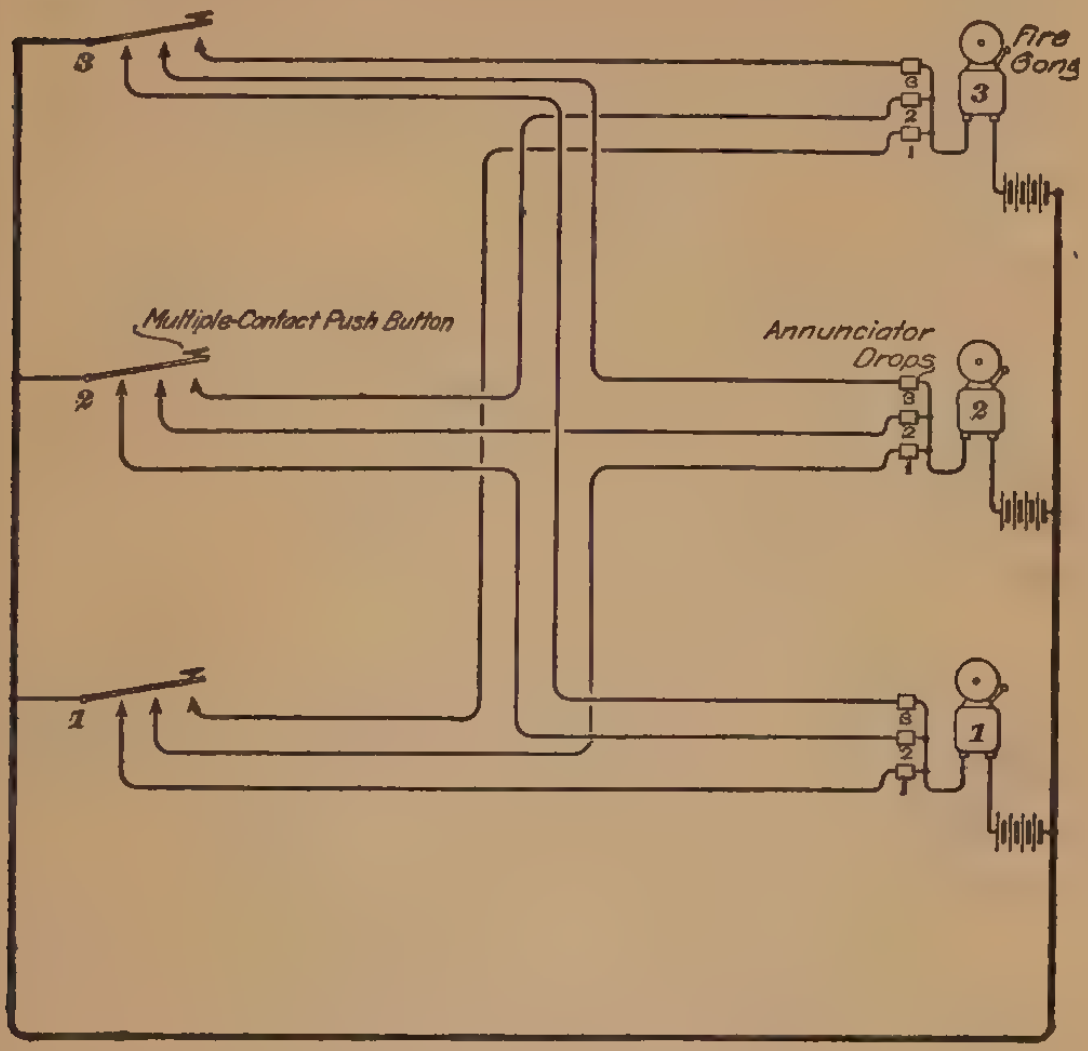


FIG. 30. FIRE-ALARM GONGS

from the hall door of the flat; also a buzzer in each flat may be rung from the rear door.

DOOR OPENERS

In apartment houses, it is often convenient for a tenant to be able to unlock the front door of the building without leaving his own apartments. This can be done by means of a special lock operated by an electromagnet wired to a push button in each apartment.

BURGLAR ALARMS

In the *open-circuit system* of burglar alarms, Fig. 32, several electromagnets are installed at some convenient point—one magnet for each circuit. A double-throw switch is usually provided for testing. When closing the house, this switch is placed on contact *1*, and the magnet switches k_1, k_2 are closed successively. If a window has been inadvertently left open, thus closing a contact spring, the corresponding drop will fall when the magnet switch is closed. The windows being all closed, switches k_1, k_2 are left closed, and the double-throw switch is placed on contact *2*. The raising of a window will then close a circuit, ring the bell, and cause a magnet drop to fall simultaneously; the drop closes a local circuit, so that, even if the window is closed again, the bell will continue to ring. The local circuit should contain about the same resistance as the circuit through the electromagnet.

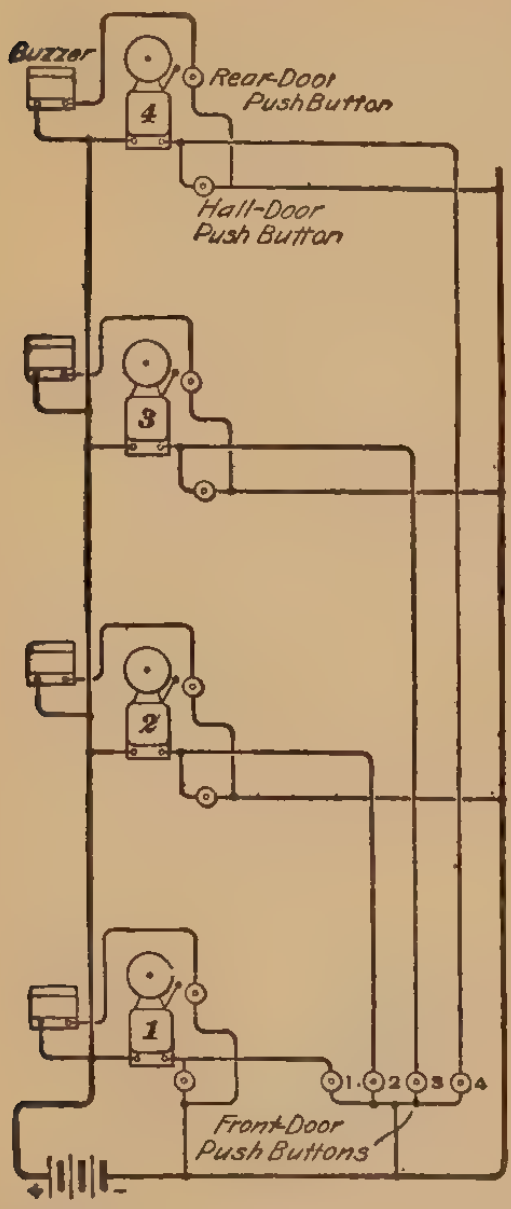


FIG. 31. WIRING FLATS

In the *closed-circuit system* of burglar alarms, Fig. 33, there is a continuous flow of current through circuits of which contacts attached to the doors and windows form a part. In these circuits are relay magnets that, when excited, hold the local bell circuit open; but if any of the main circuits are opened by opening a door or a window or by break-

ing a wire, the bell circuit is automatically closed by the release of a relay-magnet armature, and the bell rings con-

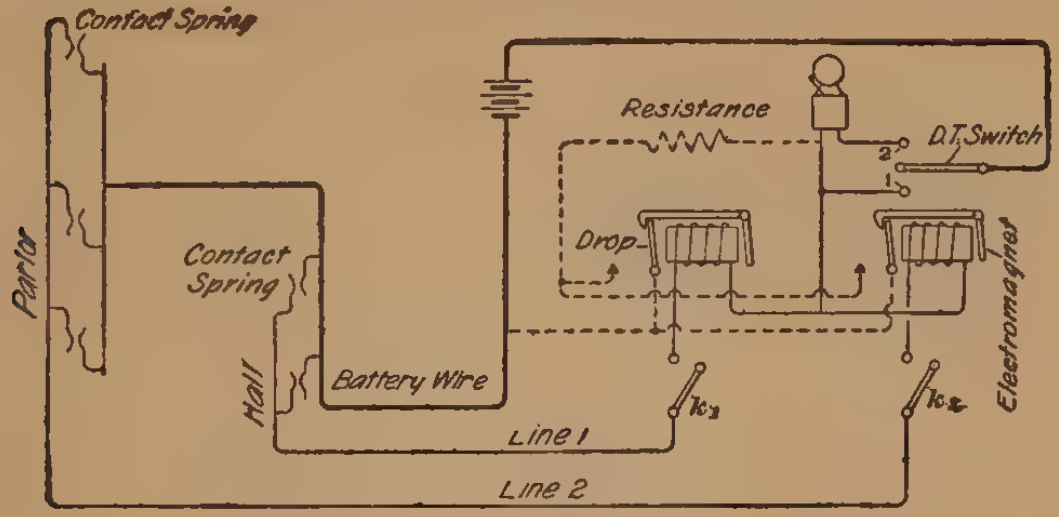


FIG. 32. OPEN-CIRCUIT BURGLAR ALARMS

tinuously until a key k_1 or k_2 is opened. These keys are left closed when the system is in use.

The two systems may be so combined that an alarm will be given if a circuit is opened or closed at a door or a window, or if the wires are broken or crossed at any point.

ELECTRIC GAS LIGHTING

The rules for installing wires for electric gas lighting are

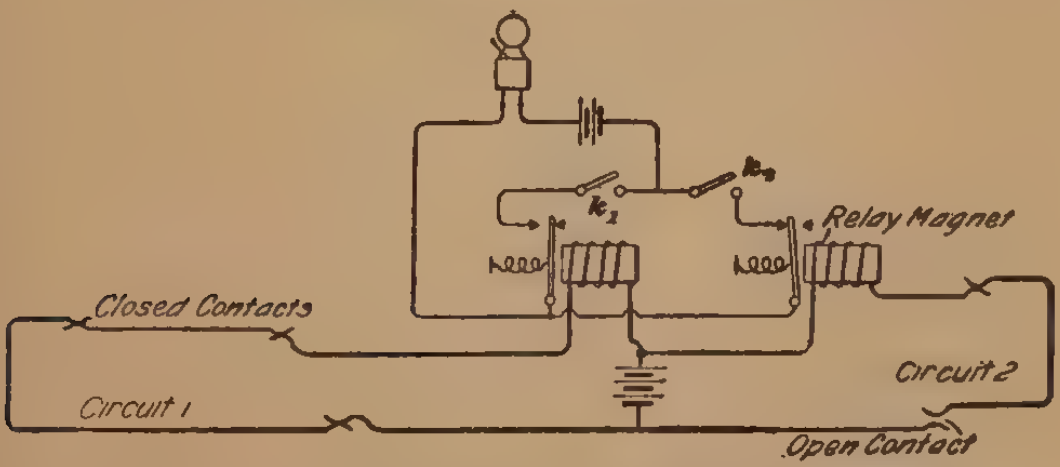


FIG. 33. CLOSED-CIRCUIT BURGLAR ALARMS

the same as for other minor appliances where the E. M. F. is not over 10 volts, except that electric gas lighting must

not be used on combination fixtures, that is, those having both gas and electric lights.

Parallel System.—In the *parallel system* of gas lighting, Fig. 34, one terminal of the battery is connected through a spark coil to the gas pipe, and the other through insulated circuits to the insulated terminals on the burners. Each burner has also a grounded terminal so arranged that it can be brought into contact with the insulated terminal, thus closing the circuit; when the contact is broken, a spark is caused in the jet of gas, which is thereby ignited.

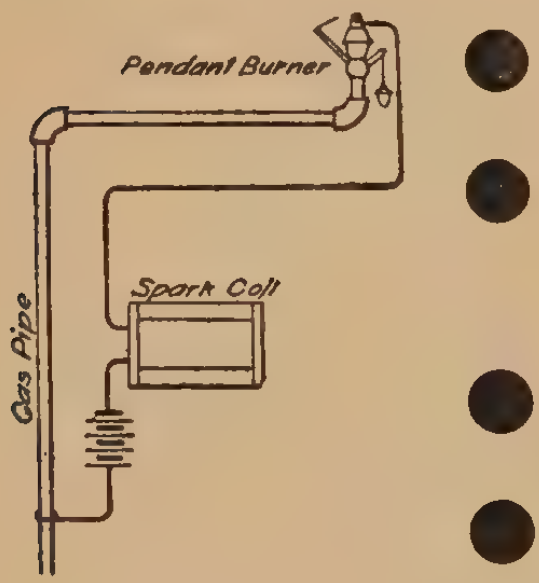


FIG. 34

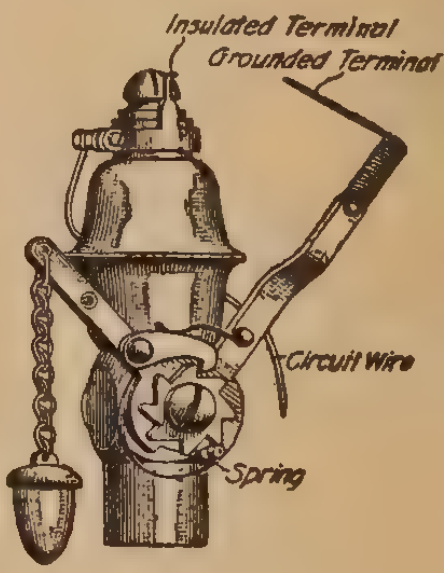


FIG. 35

Pendant Burners.—In the *Boston ratchet burner*, Fig. 35, which is typical of most pendant burners, one pull of the pendant turns on the gas and ignites it; on releasing the pendant, the grounded terminal is returned by a spring to its normal position, and a second pull of the pendant turns off the gas.

Automatic burners can be had with electromagnets so arranged that the gas can be turned on and ignited by pressing a button, and turned off by pressing another button, both buttons being located at any convenient point. Two insulated wires to each burner are required, one from each button; the gas pipe serves for the return circuit.

ELECTRIC HEATING

HEATING OF CONDUCTORS

The heat generated in a conductor in which an electric current is flowing is proportional to the square of the current I, the resistance R of the conductor, and the duration in time t of the flow; that is, the work in joules converted into heat is I^2Rt, where I is in amperes, R in ohms, and t in seconds. The temperature attained by the conductor depends on the readiness with which heat can escape. Heat escapes more readily from insulated wire in molding or conduit or even in air than from bare wire in still air; also, in still air, a wire with a rough, blackened surface will dissipate heat more rapidly than one with a smooth, shiny surface. A wire will carry a current with less temperature rise if suspended horizontally than if suspended vertically.

Fuse wires should never be less than 1 in. long, otherwise so much heat will escape to the terminals that the fusing of the wire at the current for which it was selected will be uncertain. Pure copper wire makes the most reliable fuse wire. The table on pages 342 and 343 gives the diameters of wires of various materials that will be fused by a current of given strength.

Rheostats.—In rheostats, the resistance wire is often covered with enamel or cement, to exclude the air and thus permit operating at a much higher temperature than would otherwise be safe. One manufacturer covers the resistance wire with a cement that is not injured even though the wire is white hot, and the wire itself may be operated at red heat without apparent injury. The resistance wire in rheostats is usually German silver or iron. German-silver wire is used for small current-carrying capacities, where the air can be excluded, and iron wire, mounted so as to obtain good ventilation, where large carrying capacity is desired. The circular mils per ampere for continuous safe carrying capacity of galvanized-iron wire in open air varies gradually from 1,300 for No. 0 B. W. G. to 650 for No. 18.

FUSING EFFECTS OF CURRENTS

(W. H. Preece, F. R. S.)

Current Amperes	Diameters in Inches								
	Copper	Aluminum	Platinum	German Silver	Platinoid	Iron	Tin	Tin-Lead Alloy	Lead
1	.0021	.0026	.0033	.0033	.0035	.0047	.0072	.0083	.0081
2	.0034	.0041	.0053	.0053	.0056	.0074	.0113	.0132	.0128
3	.0044	.0054	.007	.0069	.0074	.0097	.0149	.0173	.0168
4	.0053	.0065	.0084	.0084	.0089	.0117	.0181	.021	.0203
5	.0062	.0076	.0098	.0097	.0104	.0136	.021	.0243	.0236
10	.0098	.012	.0155	.0154	.0164	.0216	.0334	.0386	.0375
15	.0129	.0158	.0203	.0202	.0215	.0283	.0437	.0506	.0491
20	.0156	.0191	.0246	.0245	.0261	.0343	.0529	.0613	.0595
25	.0181	.0222	.0286	.0284	.0303	.0398	.0614	.0711	.069
30	.0205	.025	.0323	.032	.0342	.045	.0694	.0803	.0779

35	.0227	.0277	.0358	.0356	.0379	.0498	.0769	.089	.0864
40	.0248	.0303	.0391	.0388	.0414	.0545	.084	.0973	.0944
45	.0268	.0328	.0423	.042	.0448	.0589	.0909	.1052	.1021
50	.0288	.0352	.0454	.045	.048	.0632	.0975	.1129	.1095
60	.0325	.0397	.0513	.0509	.0542	.0714	.1101	.1275	.1237
70	.036	.044	.0568	0564	.0601	.0791	.122	.1413	.1371
80	.0394	.0481	.0621	.0616	.0657	.0864	.1334	.1544	.1499
90	.0426	.052	.0672	.0667	.0711	.0935	.1443	.1671	.1621
100	.0457	.0558	.072	.0715	.0762	.1003	.1548	.1792	.1739
120	.0516	.063	.0814	.0808	.0861	.1133	.1748	.2024	.1964
140	.0572	.0698	.0902	.0895	.0954	.1255	.1937	.2243	.2176
160	.0625	.0763	.0986	.0978	.1043	.1372	.2118	.2452	.2379
180	.0676	.0826	.1066	.1058	.1128	.1484	.2291	.2652	.2573
200	.0725	.0886	.1144	.1135	.121	.1592	.2457	.2845	.276
225	.0784	.0958	.1237	.1228	.1309	.1722	.2658	.3077	.2986
250	.0841	.1028	.1327	.1317	.1404	.1848	.2851	.3301	.3203
275	.0897	.1095	.1414	.1404	.1497	.1969	.3038	.3518	.3417
300	.095	.1161	.1498	.1487	.1586	.2086	.322	.3728	.3617

TINNED-IRON WIRE

No. B. & S.	Area Circular Mils	Maximum Safe Current Continuous Duty Amperes		Safe Current for 1 Minute	Feet per Ohm	Pounds per Foot	Ohms per Inch of .4-Inch Spiral
		Wooden Frame	Iron Frame				
8	16,509	17.40	20.30	43.6	250.00	.04000	.0050
9	13,094	14.60	17.10	36.6	173.00	.03300	.0066
10	10,381	12.30	14.30	30.8	137.00	.02751	.0095
11	8,234	10.30	12.00	25.8	108.00	.02182	.0131
12	6,529	8.70	10.10	21.7	86.40	.01730	.0182
13	5,178	7.30	8.50	18.3	68.50	.01372	.0145
14	4,106	6.10	7.10	15.3	54.30	.01089	.0353
15	3,257	5.10	6.00	12.9	43.10	.00863	.0492
16	2,583	4.30	5.00	10.8	34.10	.00685	.0690
17	2,048	3.60	4.20	9.1	27.10	.00543	.0960
18	1,624	3.00	3.50	7.6	21.40	.00430	.1345
19	1,252	2.50	2.90	6.3	16.50	.00341	.1963
20	1,021	2.20	2.50	5.4	13.50	.00271	.2636
21	810	1.80	2.10	4.5	10.70	.00231	.3725
22	643	1.50	1.77	3.8	8.49	.00184	.5220
23	509	1.30	1.49	3.2	6.73	.00146	.7350
24	404	1.08	1.20	2.6	5.34	.00116	1.0350

Tinned-iron wire is much used for rheostats; the wire is usually wound on iron frames, but sometimes, if only for temporary or experimental purposes, on wooden frames. The table on page 341 gives useful data, including safe carrying capacity both for continuous duty and for 1-min. periods, as for starting rheostats. The resistance per inch of a spiral wound on a 4-in. mandrel as close as possible without having adjacent turns in contact is also given.

AIR AND WATER HEATING

(1 B. T. U. = 778 ft.-lb. = 1,055 joules)

Air Heating.—To raise the temperature of 1 cu. ft. of air 1° F. requires an expenditure of about 18 joules; to make this change in 1 sec. requires an expenditure of 18 joules per sec., or 18 watts. A room 12 ft. × 14 ft. × 10 ft. high contains 1,680 cu. ft., and to raise its temperature from 0° to 70° F. in 1 hr. requires $\frac{1,680 \times 18 \times 70}{3,600} = 588$ watts, or 588 watt-hours. If the time were ½ hr., twice as many watts would be required, but the number of watt-hours would be the same. This calculation assumes no escape of heat from the room.

At the prevailing prices of electricity, electric air heaters are not practical for warming ordinary dwelling houses, except when only a slight rise of temperature, enough to remove dampness, etc., is desired. On electric cars, however, where the cost of the energy used is not a serious consideration, electric heaters are much used. For heating an ordinary electric car in zero weather, about 12 amperes at 500 volts is required, with the outside temperature at 20° to 30° F., about 6 amperes is sufficient.

Water Heating.—The weight of 1 gal. of water is 8.34 lb., and to raise its temperature 1° F. requires the expenditure of 8.34 B. T. U. or 8.34 × 1,055 = 8,798.7 joules; 8,798.7 ÷ 3,600 = 2.444 watt-hours required, provided there are no heat losses.

ELECTRIC HEATING APPLIANCES

Some of the advantages of electric heat are as follows: Its instant availability on closing a switch; its perfect control, since heat may be obtained in almost any intensity desired; its perfect adaptability, as the application may be made at almost the exact location desired, very little heat being wasted; the absence of smoke, flame, dust, poisonous gases, etc.; the absence of fuel and ashes to be handled or fires to be maintained; the reduction of danger of fire or explosions.

Domestic Heating Appliances.—All *domestic heating appliances* requiring about 500 watts or less may be classified as *lighting-circuit devices*, because no special wiring or outlets are needed. Those requiring more than 500 watts should be classified as *heating-circuit devices*, for which special circuits and outlets should be provided.

Electric flat irons, coffee pots, tea pots, water heaters, chafing dishes, stoves, plate warmers, griddles, warming pads, curling-iron heaters, etc. are already finding extensive use, and reductions in the price of electric energy will not only greatly increase their popularity, but will also introduce into many homes still larger electric-heating devices. All new houses should be wired for both electric heating and electric lighting, the heating outlets being placed as near as possible to the place where the devices are to be used.

Miscellaneous Heating Appliances.—Among *miscellaneous heating appliances* may be classed those used in printing and book-binding establishments, electric-laundry machinery, hatter's tools, tailor's irons, glue pots, soldering irons, cigar lighters, etc.

Power Consumption of Heating Appliances.—The *power consumptions* of some of the ordinary electric-heating appliances are as follows: Ordinary 6-lb. flat iron, 500 watts; 3-qt. chafing dish, 500 watts; 1-qt. water heater, to boil water with an initial temperature of 60° F. in 10 min., 650 watts; 1-qt. glue pot, 440 watts; soldering iron, equivalent to a 3-lb. soldering copper, 150 watts.

THAWING FROZEN WATER PIPES

For *thawing frozen water pipes* electrically where alternating current is available, special transformers either having large magnetic leakage or each with a choke coil in series are used. The secondary voltage is usually low, but the current is high. The large magnetic leakage or the choke coil permits the secondary of such a transformer to be short-circuited for several minutes without injury. The piece of frozen pipe is made a part of the secondary circuit, the primary terminals of the transformer are connected with the lighting circuit, and the voltage is adjusted until the desired current through the pipe is obtained. There should be the least possible resistance in the secondary circuit; that is, the secondary leads should be of ample size and as short as possible. Connections can be made at a hydrant and a faucet in a neighboring house, or to faucets in two adjacent houses, etc.

Where only direct current is available, a motor-generator or a dynamotor is necessary to reduce the voltage; a motor-generator is preferable, since the voltage is under better control. The volts, amperes, and time required to produce running water in a frozen pipe vary between wide limits and according to no fixed rule. Ordinary house piping, however, seldom requires more than 30 to 50 volts and 300 amperes.

ELECTRIC WELDING

By joining two pieces of metal, as indicated in Fig. 1, sending through the joint enough current to heat the joined surfaces to welding temperatures, and then pressing them firmly together, they may be made to cohere like solid metal. Many welding operations are economically performed in this way. The pieces to be welded are usually clamped in a device, by means of which they may be forced together with a considerable pressure. One secondary terminal of a transformer is connected with each side of the joint, and a heavy current is sent across. The large current and the high joint resistance cause the development of enough heat to raise the temperature to welding point in a

very short time, and the pieces are then pressed together and the current shut off.

Alternating current is most convenient because of the ease of its transformation. The frequency should not be over 50; the voltage required is low, depending on the nature of the work; the current density is very high, that for copper welding sometimes being as high as 60,000 amperes per sq. in.

Welding Transformer.—A *welding transformer* has very few turns—often only one—of very massive secondary copper. In some cases, the secondary is a heavy copper casting slit on one side and having a clamp each side of the slit for holding the work. The current, being of very low voltage, cannot cross the slit, but goes through the work by way of the clamps. It is sometimes necessary to provide a circulation of cold water through the clamps to keep them from overheating.

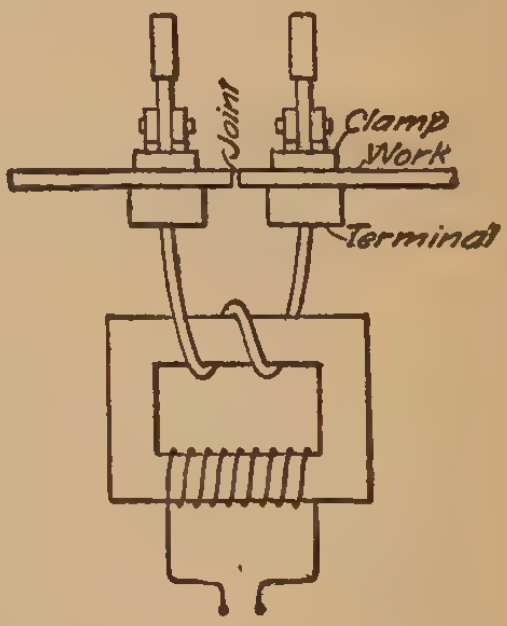


FIG. 1. ELECTRIC WELDING

Power Required for Electric Welding.—The power required for electric welding varies inversely as the time consumed in making weld, and to some extent on the metals welded. Copper, brass, tool steel, and other metals that are deteriorated by high temperatures must be heated quickly, pressed together with sufficient force to push all the injured metal out from the weld, and allowed to cool at once. Comparatively little heat is wasted, 70 to 75% of the power applied being utilized. In the table on page 192,, the areas are in square inches, the power is in watts supplied to the primary of the welding transformer, and the time is in seconds. The distance between terminal clamps was twice the diameter of the iron pieces being welded, three times the diameter for brass, and four times the diameter for copper.

POWER AND TIME REQUIRED FOR ELECTRIC WELDING

Iron and Steel			Brass			Copper		
Area Square Inches	Power Watts	Time Seconds	Area Square Inches	Power Watts	Time Seconds	Area Square Inches	Power Watts	Time Seconds
.5	8,550	33	.25	7,500	17	.125	6,000	8
1.0	16,700	45	.50	13,500	22	.250	14,000	11
1.5	23,500	55	.75	19,000	29	.375	19,000	13
2.0	29,000	65	1.00	25,000	33	.500	25,000	16
2.5	34,000	70	1.25	31,000	38	625	31,000	18
3.0	39,000	78	1.50	36,000	42	.750	36,500	21
3.5	44,000	85	1.75	40,000	45	.875	43,000	22
4.0	50,000	90	2.00	44,000	48	1.000	49,000	23